NUCLEAR ENGINEERING

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TEMPLE PRESS LIMITED

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Telephone: Terminus 3636 (Private Exchange).
Inland Telegrams: "Pressimus London Telex."
Telex: 2-3039.
Cables: "Telex 2-3039=Pressimus London."

ANNUAL SUBSCRIPTION RATE 42/- (Canada and U.S.A. $7.00) postage included.

PUBLISHED IN GREAT BRITAIN BY TEMPLE PRESS LIMITED, LONDON, ENGLAND

G.E.C. Nuclear Research and Development—No. 1

The Hot Box

Complete reliability in operation is perhaps the most vital requirement in the design of equipment installed in a nuclear reactor. Much of the research undertaken by the G.E.C. in the laboratories of its Atomic Energy Division has been towards this end. Just one of the many research tools used in this work is popularly known as the "hot box".

The "hot box" is constructed much in the form of a reactor standpipe and is designed to house all the components which will operate in a reactor standpipe.

At its lower end, beneath the laboratory floor, it is connected to an electrically heated vessel filled with the coolant gas and, by this means, conditions of temperature, pressure and atmosphere similar to those experienced in reactor operation, can be reproduced inside the "hot box". It is therefore possible to investigate the heat distribution likely to be found in the reactor standpipes, to carry out life-tests on the control-rod driving mechanism, and to check the operation of the burst-slug detection equipment and of numerous other smaller items.

This is just one of the ways in which the G.E.C. is ensuring the safe, reliable and economical harnessing of nuclear energy.

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Atomic Energy Division

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A218

NUCLEAR ENGINEERING VOL. 2 NO. 18 SEPTEMBER, 1957

The Big Ship Project

A NUMBER of reports have recently been published which could indicate that at least two groups of companies are in a position to begin immediate construction of a nuclear-propelled tanker. These are, of course, misleading. Whilst there is considerable interest in the practicability of using atomic energy for propelling ships, much development work must take place between the completion of the feasibility study and the laying of the keel or the commencement of work on the reactor vessel. Unquestionably, several companies in this country have been actively studying the possibilities of adapting the Calder Hall type of reactor to ship propulsion, and have arrived at the conclusion that the building of a nuclear vessel is today not impracticable. At the same time, it is known that the Atomic Energy Authority has had a design team examining the gas-cooled graphite-moderated reactor as a ship propulsion unit, and that their studies have led them to the conclusion that a modified Calder unit could be installed in a large ship and made to run reasonably competitively; particularly if the anticipated increase in the price of conventional fuels is realized.

Prestige or Economy

There are two possible approaches to the propulsion project. It can be argued that, because of world prestige considerations—particularly for such a traditionally maritime nation as the United Kingdom—irrespective of cost, it is imperative that the building of a nuclear-propelled ship should be started at once. On the other hand, unless the propulsion unit installed is a real prototype of an economic unit, ultimate development time for an economic unit would be increased and we should thereby lose by the project rather than gain; whatever the advantages might be in initial prestige. It is essential that the ship project, when it begins, should be realistically aimed at the commercial market.

This is not to say that the first ship must be economic; rarely is any prototype a commercial proposition—even if much of the development cost is written off as overheads—but the commercial potential must be there. One cannot help feeling that the project for a U.S. 21,000-ton cargo-passenger ship, the keel of which is to be laid next year, has been stimulated more by prestige than by economics.

Vessel Size

At the same time, the modest tonnage figure may result from a more realistic appreciation of future shipping requirements. Against the background of statements about bigger and faster oil tankers being required, a number of comments have appeared recently, such as those by the chairman of London and Overseas Freighters to the effect that it is too early for independent owners to contemplate tankers much over 40,000 tons, and by a former general manager of the Shell tanker fleet warning that Europe will have stabilized her fuel imports by 1970 and that the yards have already nearly full order books covering tankers to be delivered well into the 'sixties.

Bigger and bigger ships will be built, no doubt, in the future, but we should not wish to embark on the development of a propulsion system which would only be applicable to a very limited number of vessels. If we assume, however, that feasibility studies conducted by the U.K.A.E.A. have indicated that the Calder type shows promise of being economic for intermediate-size vessels as well as very large ones, then to bring this to a practical working design a large team of experienced design engineers must be given the project as a high priority. One of the major contributory factors to the success of the Calder project was the concentration of effort, and the large number of skilled designers who were able to devote all their energies to this one scheme. This same design team has now no real major project in hand. From the point of view of design, Calder and Chapel Cross are complete. This team therefore is the natural team to undertake the ship development. No consortium of companies at present is in a position to put the requisite number of men with the necessary experience on to this single project.

Industrial Participation

It would be unfortunate, however, if the development of the first ship were not used to familiarize industry with the problems involved and for companies to gain experience in this potentially large and valuable field of

enterprise. Furthermore, the Atomic Energy Authority does not have (and would not claim to have) a resident body of skilled marine engineers, and there is, therefore, a real opportunity for industry and the A.E.A. to work in co-operation.

Whether the contract system adopted for Calder Hall is suitable is another matter. The ultimate owner of a land-based reactor is one of the electricity authorities, whereas the ultimate owners of reactor-powered ships will be commercial concerns and these, we hope, from many countries. The shipbuilders and their associated companies have a long experience of catering for their customers' needs and of building vessels competitively. A ship must be much more than a floating box round a reactor. The available body of experience should not be wasted, and it would seem that a greater responsibility must be given to industry in the design stages (particularly with regard to the hull and the operational equipment) than with Calder Hall. The reactor itself can only be the responsibility of the A.E.A., at this juncture, and the whole design must be properly integrated.

A.E.A. Responsibility

The reactor is, of course, the core of the vessel and as any project must have a top authority—design by committee invariably being disastrous—the A.E.A. must exercise overall responsibility.

It should, however, be emphasized that, although everyone in this country is anxious that the building of a nuclear-propelled ship should be got under way as soon as possible, construction work must be delayed until initial studies and preliminary designs have shown quite clearly that the basic system is capable of development into an economic commercial proposition, not only for mammoth vessels but for ships down at least to 40,000 tons.

Why Calder?

AT first sight it may seem inappropriate that, twelve months after the first reactor at Calder Hall became critical, *Nuclear Engineering* should be publishing a list of the contractors who contributed to the construction of the power station and should analyse the components in the plant in terms of the contracting companies. One reason, of course, is that it is only over the months that one has been able to correlate all the information on main contractors and sub-contractors into one comprehensive whole, and, although the list is the most complete that has been published, it is likely, even now, that there are still some minor omissions. There is a strange reluctance on the part of main contractors to give due credit to material and component suppliers. The comprehensive list for Bradwell recently made available by the Nuclear Power Plant Company shows a refreshingly new approach to this matter and it is to be hoped that other consortia will be as generous.

Variety of Disciplines

The analysis has been produced, however, to point out the many different types of construction work that are required in a complete power station. Although many sections of the plant have involved the development of new constructional techniques, much of the plant is entirely conventional, both in general form and detail. In the early stages one of the attractions to the A.E.A. of the gas cooled graphite moderator reactor was the limited number of new techniques that were involved. Furthermore, even the equipment which has been developed especially for the atomic energy programme, generally requires the same types of machine tools and constructional skill that are familiar in more conventional engineering structures. Nuclear engineering is a logical development of the disciplines that have developed over the years. Even the "fail-safe" design philosophy that must be adopted throughout the plant is not essentially new, but is an accentuation of a generally-accepted precept in engineering design. Inaccessibility once plant is operating can introduce special maintenance problems but in many industries this effectively applies. Similarly operation by remote control is not confined to atomic energy plants, although failures could have more serious consequences.

First Exhibition

The analysis is also timed to coincide with the first engineering exhibition in this country at which items of equipment for nuclear power stations will be displayed, viz., the Engineering, Marine, Welding and Nuclear Energy Exhibition. These items are reviewed in this issue and the pattern is again repeated, of mainly conventional plant, with some standard equipment modified for particular purposes, and some especially developed for the nuclear power stations, but all engineering of a type familiar to everyone. Perhaps the most outstanding feature of the nuclear exhibits is the quality of construction. Safety considerations demand the highest standards in constructional work and, invariably, reliability must take precedence over cost.

Finally it should be said that no excuse is needed for re-examination of the world's first large scale nuclear power station. Although there are now three commercial power stations under construction in the United Kingdom and a fourth will be started this month, Calder is still the prototype for them all and is still the only operational large scale nuclear power station in the world and, furthermore, is not likely to have a competitor for at least another five months.

Commentary

Sir Christopher's Appointment

The announcement that Sir Christopher Hinton was to be the Chairman of the new Generating Board has caused some surprise in nuclear engineering circles. There is, of course, no person better equipped to fill this position; with the coming changes in the C.E.A. both in the terms of reference of the Generating Board and in the plant it will have to consider, it is essential that the chairman should have been initially connected with the field of nuclear generation. The surprise stems from the known enthusiasm of Sir Christopher for the projects still to be got under way. Notably amongst these are the ship project and the high temperature gas cooled project, both of which were likely to come directly under his jurisdiction. It has been suggested that his decision to take the appointment could have been influenced by an impending change in the responsibilities of the Industrial Group. Although normal evolution will imply a steady change in emphasis in the work of Harwell, Risley, industry and the electricity authorities, there are no indications that the present position would not be effectively maintained for many years. It is unlikely also that Sir Christopher's move will alter this position, except that there will certainly be a shift in the balance of the power between the C.E.A. and the A.E.A. Sir Christopher leaves behind him a most competent team, but one cannot help feeling that however pressing the needs of the generation authority for new leadership, the Atomic Energy Authority has even more to lose.

Beryllium

One of the main lines of development aimed at improving the steam conditions obtainable from the gas cooled graphite moderated reactor concerns material for fuel element cans and at first sight beryllium offers many advantages over the Magnox alloys. The thermal neutron cross-section of beryllium is low; it is at the same time a good moderating material and its melting point is high. Compatibility with uranium is not so straightforward. From a fabrication point of view, however, beryllium is an intractable substance. Very high purity metal has been produced which shows reasonable ductility but preparation techniques are difficult and there is a great difference between producing sample pieces and complex finned tube which can be guaranteed completely sound. Whilst only extensive effort is likely to develop the necessary techniques for large-scale production, too great a concentration on one aspect can have its dangers. We have previously emphasized the value of the big design effort and the delays that occur when only small units are working on one project, but if the national effort is to be concentrated on one material only then we must be very sure it is the right material.

Present evidence would tend to suggest that beryllium is always going to be a difficult metal to handle and although moderator production of the metal or oxide should not be impossible the development of fuel cans is likely to be a long and tedious business and the possibility of ultimate failure cannot be ruled out. The cermet type of fuel elements would appear to offer greater chances of success and if a sheath material to the elements is considered necessary it may well prove better in the long run to use, say, stainless steel and compensate the drop in reactivity by some enrichment. In this country particularly, the use of natural uranium in preference to slightly enriched uranium has many advantages, but these advantages are lost if the elements produced are essentially fragile or highly expensive. It would be convenient if beryllium could be made as tractable as aluminium but the likelihood of this seems small. We should be well to have an equally-strong second string to our bow.

Heavy Water

Increasing interest is being evinced in the use of heavy water as a moderator not only for research and materials testing reactors but also for power reactors. It is highly likely that the decision will be taken at the end of this year to go ahead with a gas cooled heavy water project as the most promising system for medium size plant. Further impetus should also be given by the co-operation now agreed with Norway over the Halden reactor, which may point the way to the development of electricity generation/process steam plants. In Canada, of course, there is great belief in heavy water for power reactors and although work has been stopped on the original NPD project the re-thinking going on does not involve the moderator material. Germany is planning at the moment seven experimental reactors of varying size and it is unlikely that her interest will be confined to such reactors only.

In this country, following the disappointment of the New Zealand scheme, research has been continuing into the hydrogen distillation and dual chemical exchange processes. In the first of these hydrogen is distilled at around -235° C and an engineering design study particularly with reference to the reversing heat exchangers is under way. A closed cycle form of the process is also being developed. Heat conservation is also a critical feature of the dual temperature chemical exchange process between H_2S and water and a theoretical design study has been completed. An alternative exchange process between liquid ammonia and hydrogen is under investigation.

It has now been officially stated that provided the annual demand for heavy water amounted to 100 tons Britain could manufacture at a cost competitive with the present U.S. price of $28/lb.

Although the heavy water charge in a reactor can be considered as a very long term investment and the annual replacement weight a negligible figure, it should be possible at this juncture to foresee a demand in the not so distant future of the order of 100 tons per annum. A modest reactor such as DIDO will require a total initial charge of the order of 15 tons and larger installations correspondingly greater amounts. Materials testing reactors and homo-

geneous experiments should create a demand approaching 50 ton/y and it is not difficult to foresee a power reactor demand of the same order of magnitude. Whether the plant is built in this country or elsewhere in the Commonwealth it would appear that its construction is warranted as soon as a flow sheet can be finalized.

Pumped Storage

The potentiality of pumped storage as a means of increasing the effective load factor of nuclear power stations has passed through a number of phases. It now appears to be receiving more earnest consideration than previously. The North of Scotland Hydro-Electric Board has already surveyed possible sites for such installations (not necessarily in connection with nuclear stations), two near Loch Lomond and one at Loch Awe. Any one of these could be made to link up with the South of Scotland station at Hunterston. The C.E.A. has recently confirmed that planning permission is to be sought for their fourth nuclear power station (capacity 400-500 MW) to be built at Trawsfynydd, five miles south of the 500 kW Ffestiniog pumped station on the shores of the Maentwrog 24 MW hydro-electric station reservoir.

The close proximity of the Welsh nuclear and pumped storage sites will now give a real opportunity of assessing the overall efficiency of the scheme and of determining the capital and operational costs. With a nuclear station the difference between the price per kWh operating at 80% load factor and 40% can amount to 0.3d.

It should also be worth considering the coastal areas as sites for pumped storage schemes using sea water. Although it would be almost impossible to link a nuclear power station with a tidal station, there must be a number of places where inlets from the sea could be used as reservoirs. There could then be pumped storage schemes in places nearer the load centres and suitable reactor sites. Cooling water would at the same time cease to be a problem and although it would be difficult to produce large heads of water there should be no problem in volume; in general the necessary conditions for successful operation are large volumes of water and a relatively small head.

The proposed fifth site at Edern in North West Wales could present an opportunity for a large scale experiment.

Draft Factory Regulations

The Ministry of Labour and National Service has issued a preliminary draft of regulations designed to safeguard workers employed in industry against the effects of ionizing radiation. The regulations have been published in draft form to give various organizations who are involved an opportunity of considering them and discussing them with the Ministry. Comments should reach the Ministry by October 31, and should be addressed to the Secretary, Ministry of Labour and National Service.

The regulations are largely aimed at those factories employing X-rays or radioisotopes for radiography, gauging, etc., and have been drawn up realistically to assist companies to use apparatus with the maximum of efficiency and the maximum safety. In general these official regulations will be welcomed as it has been a source of concern, particularly to companies manufacturing equipment for installation in works, that no hard and fast rules were in existence which could be authoritatively put to the purchasing company. Similarly some companies have been chary of introducing radioactive materials into their factories when no official regulations existed for their use and control.

The draft is introduced by a series of definitions which should serve to clarify any apparent ambiguities in the subsequent text. The regulations apply to both X-ray and radioisotopes but not to sealed sources which on the surface cannot give a dosage exceeding 10 mrad/h. The main items in the recommendations concern permissible dosages for persons employed in the processes, those not directly employed in processes, recommendations for the handling of sources, monitoring equipment required, and medical examinations. In certain circumstances the Chief Inspector can give exemption from the regulations when he is assured that their application is unnecessary. The regulations emphasize the need for proper case histories being made of all sources handled, by the keeping of registers and the recording of movements of the sources.

It is not clear, however, in what cases exemption would be given to the use of films and dosemeters for checking the radiations round operating equipment. If for example all factories using beta gauges must be equipped with health monitors then the supply of these instruments must be very considerably increased. It should be noted that in the recommendations also, no person under the age of 18 can be employed in a process involving radiation. This would appear to affect the position of many laboratory assistants in development establishments and young people working on production lines that use radiation gauges. Some clarification is also needed of the terms "employed in the processes" and "not employed" as a liberal interpretation would involve a very large number of people in monitoring and medical examination.

The following table gives the maximum permissible levels for the two types of employees and for various types of ionizing radiation.

CONDITIONS		
Type of ionizing radiations	For persons employed in the processes	For persons not employed in the processes
X- or gamma radiation with a half-value layer of 1 mm or more of water, other than the ionizing radiations that are referred to in the third section of this table.	(i) The maximum weekly dose shall be not more than 0.3 rad. (ii) No person shall receive more than 50 rad in any decade.	The maximum weekly dose shall be not more than 0.03 rad.
X- or gamma radiation with a half-value layer less than 1 mm of water.	The maximum weekly dose at the skin shall be not more than 1.5 rad.	The maximum weekly dose at the skin shall be not more than 0.15 rad.
X- or gamma radiation with a half-value layer of 1 mm or more of water, that is restricted mainly to the hands, forearms, feet, ankles, head (excluding the eyes) and neck.	(i) The maximum weekly dose at these parts of the body shall be not more than 1.5 rad. (ii) Insofar as the ionizing radiations affect parts of the body other than those mentioned in the first column of this section, the conditions in the first section apply.	(i) The maximum weekly dose at these parts of the body shall be not more than 0.15 rad. (ii) Insofar as the ionizing radiations affect parts of the body other than those mentioned in the first column of this section, the condition in the first section applies.
Beta-rays.	(i) The maximum weekly dose in the lenses of the eyes shall be not more than 0.3 rad. (ii) The maximum weekly dose at the skin shall be not more than 1.5 rad.	(i) The maximum weekly dose in the lenses of the eyes shall be not more than 0.03 rad. (ii) The maximum weekly dose at the skin shall be not more than 0.15 rad.
Neutrons, alpha particles or protons.	(i) The maximum weekly dose shall be not more than 0.03 rad. (ii) No person shall receive more than 5 rad in any decade.	The maximum weekly dose shall be not more than 0.003 rad.

URANIUM—

and its Alloys

By R. W. NICHOLS, B.Met., A.I.M.
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The mechanical, physical, chemical and metallurgical properties of uranium are of great interest because of its importance as a nuclear fuel. In this article selected values for these properties are given and the effects of irradiation, thermal cycling, fabrication history and alloy additions are discussed.

ALTHOUGH other fissile materials can be produced by neutron absorption and decay processes, the only naturally occurring nuclear fuel is the 235 isotope of uranium which constitutes about 0.7% of natural uranium. The CO_2-cooled thermal reactors which form the first part of the U.K. nuclear energy programme are designed to use natural uranium metal as their fuel, either unalloyed or with small (up to about 1 atom%) alloying additions, and intensive study has been made of these materials. The physical properties of interest are thermal conductivity, thermal expansion and the temperatures at which phase changes occur.

The central temperature of an element of a specified design and surface temperature is dependent upon the conductivity of the fuel. This central temperature may be limited to the temperature at which either a solid/solid or a solid/liquid phase change occurs because of the associated changes in volume of the fuel at this temperature. Thermal expansion and the elastic moduli govern the magnitude of the stresses and strains induced in the fuel due to temperature gradients, and those produced in both the fuel and can because of differential thermal expansion. The possibility of interaction between can and fuel is of obvious interest as the use of non-compatible metals would necessitate separating the can from the core without seriously impairing the heat transfer properties. The compatibility of the fuel with the coolant must be sufficient to prevent catastrophic reaction in case of penetration of the can. Dimensional stability under reactor conditions is desirable to minimize can failure and to avoid difficulties in the removal of the fuel element; this necessitates knowledge of the creep properties, especially at low stresses under irradiation, and also the resistance of fuel to thermal cycling and irradiation effects. With the increasing availability of enriched fissile material, larger alloying additions are of interest since these can result in appreciable modification of these properties and better irradiation resistance. Some of the possibilities are discussed in later sections.

Occurrence, Extraction and Preparation of the Metal

The earth's crust contains about 0.0003% of uranium, it being an important constituent of nearly 100 mineral species of which impure oxides are the most important. Although high-grade deposits are scarce, uranium ores frequently occur in association with other commercially valuable ores as, for example, in Canadian pitchblende which contains appreciable amounts of gold and silver. In the extraction process currently used in Britain the crushed ore is dissolved, precipitated and redissolved in nitric acid and a purified uranyl nitrate solution is then obtained by extraction with an organic solvent in a continuous process. Ammonia precipitation followed by hydrogen fluoride gas reaction leads to uranium tetrafluoride which is then reduced to the metal by firing with metallic calcium or magnesium. Since commercial-grade magnesium generally has fewer contaminants than commercial calcium and also because a smaller proportional weight is necessary for the reduction process, magnesium reduction leads to a purer product. The impurity levels are of the order of 800 ppm carbon, 175 ppm iron, 100 ppm nitrogen and 300 ppm aluminium for calcium reduction processes and 200-300 ppm carbon, 100 ppm iron for magnesium reduction.

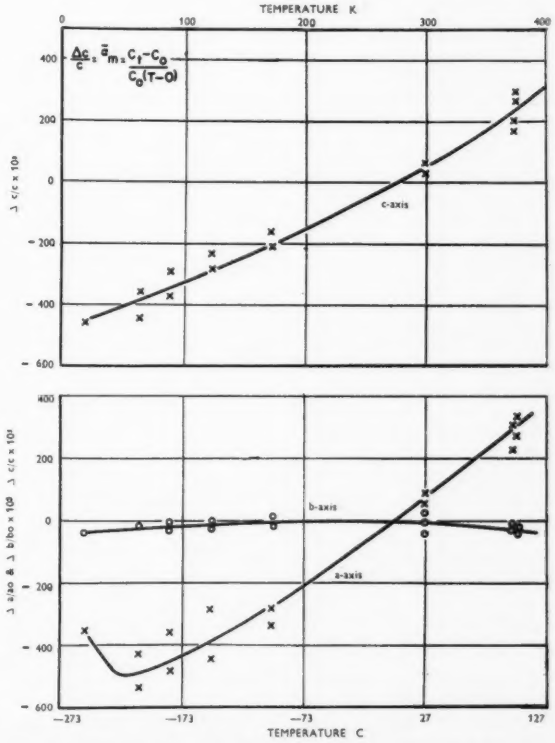

Fig. 1.—Mean change in length per unit length for each of the crystallographic directions over the temperature range −253° to +100°C[21].

Since the impurities normally present in uranium have great effects on both the properties and heat treatment response, it is common practice to adjust the impurity content by additions to the individual billets. The final melting is normally done in vacuum HF furnaces and leads to a considerable reduction of the hydrogen content of the metal; the use of graphite crucibles and moulds can result in an appreciable carbon pick-up especially where large additions of alloying elements that raise the melting point of uranium (e.g., molybdenum and zirconium) are used.

TABLE 1

Effect of Rolling Temperature on Mean Thermal Expansion Coefficient[2]

Nominal rolling temperature (°C); Uniform 75% reduction in area	Mean thermal expansion coefficient (25–100°C) × 10^6 units/unit/°C	
	As rolled	Recrystallized at approximately 625°C
300	8.5	6.8
400	9.3	7.9
500	11.4	9.2
600	12.9	—
640	14.1	—

Physical Properties

Certain of the physical properties such as density, specific and latent heats, vapour pressure, thermal conductivity and phase-change temperatures are relatively independent of the prior metallurgical history or, within limits, the exact state of purity of the sample. Uranium can exist in three allotropic forms; between 769°C and the melting point in unalloyed uranium the stable phase is body centred cubic (gamma) which is isotropic in its properties. Alpha uranium, an orthorhombic structure stable up to 662°C shows appreciable variation in certain properties when these are measured along different directions of a single crystal. For example, the thermal expansion in the three principal mutually perpendicular directions of a uranium crystal can be deduced from X-ray data and these are shown in Fig. 1. The same is true to a lesser extent in the case of the tetragonal beta phase (stable from 662-769°C). Because plastic deformation occurs more easily along certain directions of the individual crystals within a polycrystalline bar, fabrication processes, such as rolling and drawing, produce material in which these individual crystals tend to be aligned with certain crystallographic directions parallel to the direction of working.

The actual preferred orientation depends on the nature of the working process and the temperature at which it is done; the amount of preferred orientation can be considerably reduced by heat treatment, such as quenching from temperatures within the beta range. Because of these effects wrought uranium can show considerable variation from sample to sample in directionally dependent properties such as elastic moduli, thermal expansion, and mechanical strength. The magnitude of this variation in elastic properties with mode of preparation is shown in Fig. 2. Variation in thermal expansion and tensile properties with

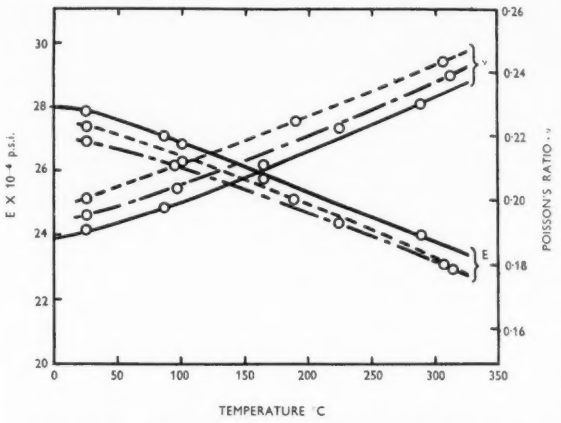

Fig. 2.—Variation with test temperatures of the elastic constants of uranium samples prepared by three different rolling techniques[2]. Rolling temperatures were as follows :— ——630°C ; - - - -550°C ; —·—·-480°C.

fabrication history are shown in Tables 1 and 2, while average values have been included in the data sheet. These variations are likely to be less marked in fine grained, cast and heat treated materials which have effectively random orientations. The anisotropic behaviour of the individual crystals is, however, still important in such cases because of the stresses induced between grains on change of temperature.

When uranium is heated through the alpha-beta transformation temperature a volume expansion of 1% occurs. Because this phase change does not occur over the whole sample at the same instant, local plastic deformation occurs under the action of the stresses produced by the differences in volume at the boundary between the beta and alpha phases. This phase boundary sweeps on progressively under the action of thermal gradients until the whole specimen has been affected. Similar effects, which in practice are additive to those produced on heating, occur on cooling from the beta to the alpha phase.

The eventual result of repeated heating and cooling through a temperature range in which phase transformation occurs (e.g., 630-690°C) is a change in shape such as an increase in diameter with an associated decrease in length. The direction of this change of shape is somewhat indeterminate as is indicated by the behaviour of three similar annular specimens thermally cycled together (Fig. 3). Direction is thought to be largely dependent on the direction in which the phase change occurs which in turn is governed by the thermal gradients within the uranium. Because of the directionality in properties of the surface grains the change of shape is associated with a wrinkling of the surface. A decrease in density also occurs because of the formation of voids under the dilational stresses in the softer phase. This decrease of density appears to be more marked in uranium initially of low density (Fig. 4), but a value of about 3% per 500 cycles would be typical of present production material.

TABLE 2

Effect of Fabrication History on High Temperature Tensile Properties[2]

Test temperature (°C)	Rolling temperature (°C)	Annealing* temperature (°C)	U.T.S. (tons/sq in)	0.2% yield strength (tons/sq in)	Elongation (%)
R.T.	300	600	49.5	19.2	6.8
R.T.	300	700	28.6	10.9	8.5
R.T.	600	600	39.5	11.6	13.5
R.T.	600	700	28.6	11.2	6.0
300	300	600	15.6	7.8	49.0
300	600	600	14.3	8.5	43.0
300	600	700	12.1	6.9	33.0
500	300	600	5.0	2.3	61.0
500	300	700	4.7	3.2	44.0
500	600	600	4.7	2.5	57.0

*Annealing time 12 hours, slowly cooled from annealing temperature.

Fig. 3.—Three Mg-reduced uranium annuli thermally cycled through the α-β transformation temperature. Top: before cycling. Middle: after 100 cycles. Bottom: after 350 cycles [8].

In view of the economic advantages resulting from higher temperatures of operation means of preventing these effects are of interest. The change of shape and surface wrinkling can be considerably reduced by use of a strong can; the occurrence of the beta phase can be completely avoided by large (over 10 at. %) additions of gamma stabilizing elements such as molybdenum, niobium, and zirconium. Smaller alloying additions (e.g., $\frac{1}{2}$ at. % chromium or molybdenum) can produce appreciable improvements by altering the relative strengths of the two phases, by altering the mechanism or volume change on transformation or by slowing it down so that it does not occur within the cycling period (Fig. 5).

Mechanical Properties

The mechanical properties of uranium are highly dependent upon the fabrication and heat treatment history as well as on the impurity content of the material. Thus many reported results are of doubtful value since the impurity content of the specimens is not quoted. The ultimate tensile strength of cast uranium at room temperature is of the order of 36 ton/in^2. The room temperature UTS of extruded metal, however, decreases with increasing extrusion temperature and varies from 57-42 ton/in^2. Alpha or beta rolled material which has been subsequently alpha annealed has a strength similar to that of the extruded metal; annealing within the beta rather than the alpha temperature range produces an appreciable decrease in strength. These changes in strength may be accounted for by orientation differences or by differences in grain size caused by beta annealing or beta working.

The strength of a particular sample decreases fairly rapidly with increasing temperature in the alpha range, but an appreciable increase is obtained as the temperature rises into the beta phase which is followed by a decrease to a very low value where the gamma phase is present. The limit of proportionality is low and ill defined even at room temperature, being about 1.5-2.5 ton/in^2. It becomes even less well defined as the temperature increases, the stress strain curve showing curvature at very low levels. This makes the determination of Young's Modulus by static methods very difficult and values at room temperature ranging from $15.8\text{-}30.0 \times 10^6$ lb/in^2 have been reported. Since the value would be expected to vary in different crystallographic directions, orientation effects can account for some of the wide variations in values. Average values together with some obtained by dynamic methods have been included in the data sheets. The variation with temperature is shown in Fig. 1.

The ductility of uranium as measured by elongation in the tensile test is also very specimen dependent. Room temperature values of 5-15% and values at 500°C of 5-57% have been reported. Reasonable ductility is found for the beta phase although earlier results suggested that this phase was relatively brittle. Very high ductility is evident in the gamma phase.

TABLE 3

Effect of Carbon Content on Room Temperature U.T.S. of Cast Uranium[3]

Carbon content ppm	Total impurities ppm	U.T.S. tons/sq in	Elongation % on 2 in
60	260	23.2	8
210	410	23.7	8
360	525	26.4	8
550	650	32.1	11
630	815	33.5	17
710	1,000	31.3	12
820	925	27.8	9
1,250	1,800	33.0	10

The different impurity levels given by calcium and magnesium reduction have been shown to cause appreciable differences in creep and tensile strength. Increasing the carbon content of cast uranium has been shown to increase the tensile strength (Table 3).

As with other metals, the tensile properties of uranium can be improved appreciably by alloying additions although the possibilities are somewhat limited by the low solubility of other elements in alpha-uranium. A number of elements such as aluminium and silicon form hard intermetallic compounds which improve the mechanical properties when present in small amounts; with larger additions the brittleness of these compounds makes fabrication difficult.

The elements which can dissolve to an appreciable extent in alpha-uranium are chromium, molybdenum, niobium, ruthenium, titanium, vanadium and zirconium. With these metals solid solution hardening can be achieved and a yield strength at 500°C of from 3 to 5 times that of uranium has been reported for small additions of chromium and zirconium (Table 4). A marked increase in the room temperature UTS has also been found for small

molybdenum additions (Table 5); the range of values quoted in this table arises from the possibility of hardening by quenching from a high temperature when a metastable solid solution is formed in a similar way to martensite in steel.

TABLE 4

Tensile Properties of Uranium and Some Alloys at 500°C[4]

Analysis Wt.%	Grain size mm	Ultimate tensile strength (tons/sq in)	0.2%yield strength (tons/sq in)	Elongation on 2 in (%)	Reduction of area (%)
Base Uranium .. (<0.01 C)	>0.118	5.0 5.6	3.7 3.5	26.0 29.0	~78 ~87
U–0.10 Chromium .. (<0.01 C)	0.057	14.1 11.6	10.4 6.8	24.5 25.5	~57 ~85
U–0.42 Chromium .. (<0.01 C)	0.025	17.3 16.6	11.0 10.6	23.0 23.0	82 82
U–1.11 Zirconium .. (<0.01 C)	0.033	19.4 27.1	14.0 21.5	11.3 21.0	61 94
U–2.21 Zirconium .. (<0.01 C)	0.009	20.6 23.4	18.5 20.1	18.0 24.0	85 94

Such heat-treatments are of limited value where the uranium is to be used under irradiation at high temperatures because of the annealing effect of the service conditions. High strengths at temperatures up to 600°C have been found for alloys containing larger amounts of niobium, zirconium (Fig. 6) and molybdenum (Table 6) in which the gamma phase can be retained by quenching to room temperature.

TABLE 5

Ranges of Room Temperature Tensile Properties Obtainable in Uranium-Molybdenum Alloys by Various Heat Treatments[5]

	Uranium*	U–½ w/o Mo	U–1 w/o Mo	U–2 w/o Mo
U.T.S. (tons/sq in) ..	26.5–46.5	44.5–83	51.5–87	48 –86
Yield stress (tons/sq in) ..	9.5–18	21.5–41.5	24 –62	24– 86
Elongation (%)	18 –18	6 –43	2 –31	0.2–21
V notch impact (ft lb) ..	18 –38	3 –15	4 –13	2 –18

*Depends on impurity (especially carbon) content and fabrication history.

High strengths are especially found where the composition and heat treatment is such that the uranium and alloy atoms in the solid solution are arranged in regular order (gamma′ phase), rather than mixed randomly on the lattice sites as they are in the normal gamma phase. These alloys are all relatively brittle and show considerably lower elongation to fracture than unalloyed uranium at a similar temperature.

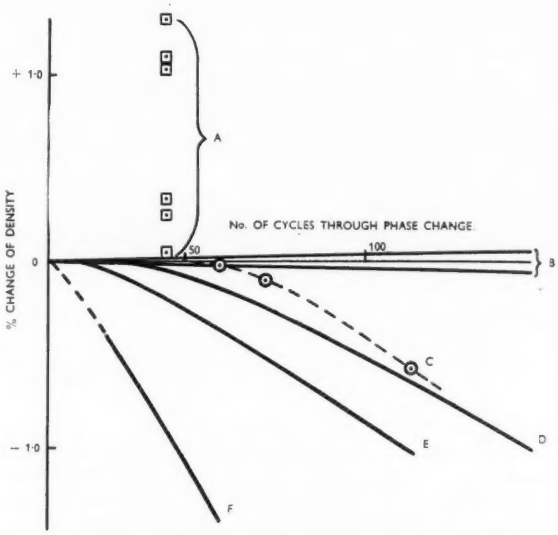

Fig. 4.—Effect of thermal cycling on the density of uranium (after Waldron, Buckley and Harding) [11].
A.—Sintered powder compact β-γ cycled.
B.—Cast or cast and swaged uranium β-γ cycled.
C.—Cast high purity electrolytic uranium.
D.—Cast and swaged (30% reduced) uranium, α-β cycled.
E.—Cast calcium-reduced uranium α-β cycled.
F.—Sintered powder compact α-β cycled.

As in mild steel, the nature of the fracture of uranium is very dependent on the temperature. Above a certain temperature under particular conditions it is ductile, whereas below this transition temperature it is brittle. This transition temperature varies markedly with the purity and condition of the material and with the nature of the stressing conditions. In notch impact tests such as the Izod the temperature is usually between 50 and 150°C (Fig. 7), whereas in the tensile test the marked decrease in ductility occurs at testing temperature below −20°C. Fortunately uranium is normally used in relatively small sections, statically loaded at high temperatures and this

TABLE 6

The Effect of Molybdenum Additions on the High Temperature Tensile Strength of Uranium[6]

Temperature (°C)	Property (U.T.S. tons/sq in) Elongation, per cent on $4\sqrt{A}$ gauge length	As cast Mg-reduced Uranium	Molybdenum content (weight %)						
			All alloys vacuum H.F. cast into graphite ; forged, rolled and heat treated 900°C for 7 days water quenched						Extruded
			2.2	4.6	6.6	7.8	10.0	10.9	10.9
100	U.T.S.	—	36.0	—	—	—	—	—	80.0
	Elongation	—	—	—	—	—	—	—	5.6
200	U.T.S.	20.2	—	38.4	42.7	38.4	37.0	—	73.5
	Elongation	24.0	—	12.0	4.0	6.0	0.5	—	6.5
300	U.T.S.	15.3	—	—	42.8	—	—	—	64.0
	Elongation	30.0	—	—	6.5	—	—	—	4.5
400	U.T.S.	7.1	—	32.7	43.5	35.6	26.1	25.5	56.6
	Elongation	28.0	—	5.0	3.0	9.0	1.0	0.5	3.0
500	U.T.S.	—	—	—	—	—	—	—	—
	Elongation	—	—	—	—	—	—	—	—
600	U.T.S.	3.7	—	12.4	—	25.0	12.9	9.4	—
	Elongation	42.0	—	7.0	—	5.0	—	0.5	—
700	U.T.S.	5.8	2.4	—	2.6	—	—	10.6	—
	Elongation	13.0	66.5	—	70.0	—	—	1.0	—
800	U.T.S.	—	1.8	—	1.1	4.1	4.1	6.6	—
	Elongation	—	81.0	—	94.0	69.0	30.0	6.0	—

brittle behaviour is not important except in so far as it affects processing of irradiated elements.

Creep Properties

The results available on the creep properties of uranium are few in number and show a wide variation in properties. This is due both to the marked differences between different materials and to the difficulties in carrying out the tests. It is essential that such creep tests are performed under good vacuum or inert atmosphere conditions, especially where the specimen is small in diameter and in apparatus where the growth of any oxide film can affect the accuracy of strain measurement. Because of the anisotropic thermal expansion of uranium, the variation of temperature during a test must be kept to a minimum; it can be shown that a temperature variation of $\pm\frac{1}{2}$°C can produce stresses between the individual grains of about 300 lb/in². As a result of these stresses, thermal cycling can increase the creep rate of uranium (Table 7). With very large temperature variations, such as repeated cycling to room temperature from 400°C, the internal stresses resulting from the differences in expansion between the different grains are sufficient to produce primary creep or even plastic deformation on each cycle, resulting in a very high apparent creep rate (Fig. 8).

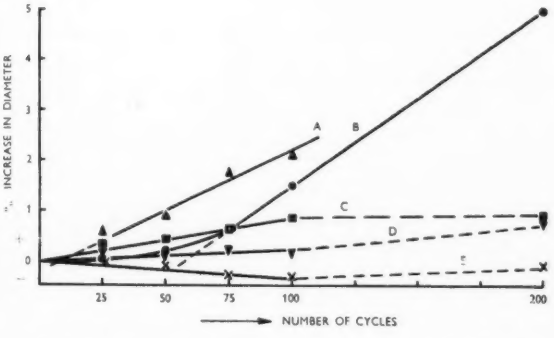

Fig. 5.—Effect of alloy additions on the dimensional stability of uranium, thermally cycled through the α-β phase transformation temperature [6].
A.—Ca-reduced uranium.
B.—U—2.08 at. % V.
C.—U—4.20 at. % Mo.
D.—U—0.47 at. % Mo.
E.—U—0.55 at. % Cr.

The creep strength of uranium is highly dependent on its composition and grain size. Heat treatments of cast uranium, such as quenching from a temperature within the beta-range, which produce a fine grain size also reduce the creep strength at the temperatures of reactor interest where creep is predominantly at the grain boundaries. Because of these factors, as-cast calcium reduced uranium showed an appreciably higher creep strength than the purer as-cast magnesium-reduced metal (see Fig. 9). By adjusting the impurity levels of the individual billets and by heat-treating the materials to a comparable, fine grain size, this difference in creep strength can be considerably reduced. The values quoted in Table 8 show no significant difference in secondary creep rate at 400°C 3 ton/in².

TABLE 7

Effect of Thermal Cycling on Creep of Uranium[7]

Material	Creep strain (%) after 400 hours on thermally cycling through range shown			Stress lb/sq in
	472–500°C	493–500°C	499¼–500¼°C	
Rolled at 600°C then alpha-annealed ..	5.1	2.2	0.55	1,500

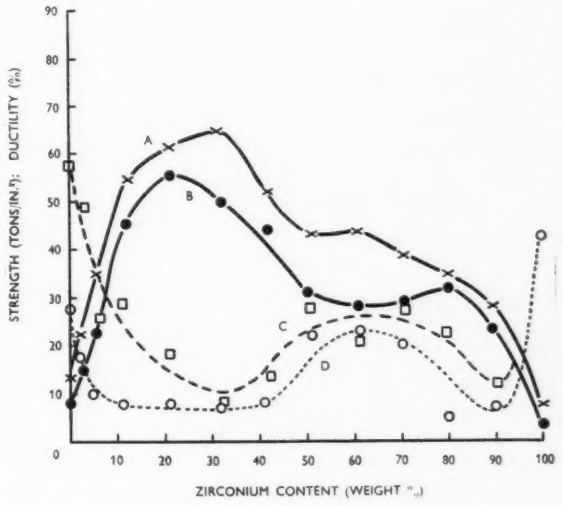

Fig. 6.—Tensile properties of arc melted uranium-zirconium alloys at 370°C [4].
A.—Ultimate tensile strength ton/in².
B.—0.2% yield strength ton/in².
C.—Reduction of area %.
D.—Elongation on 2 in. %.

Under reactor conditions the uranium is subject to only low stresses and slow strain rates which are most difficult to achieve experimentally in tensile creep machines. The alternatives are extrapolation from data covering a range of stresses and temperatures or the use of bend test techniques. Creep results over wide ranges of stress and temperature are only available for as-cast material and these are included in the data sheet; the nature of the curves makes extrapolation difficult and uncertain, especially when applied to material in other conditions. The bend test results at low stresses suggest somewhat higher creep rates than would be expected from these extrapolations, although part of this difference may arise from the thermal cycling of the bend specimens when they were repeatedly removed from the furnace for measurement.

The effect of alloying additions on the creep strength of as-cast and grain-refined uranium has been studied in tensile tests at 500°C, 2 ton/in². Alloy additions also affect the grain size of the uranium and this must be remembered in consideration of the results (see Table 9). Titanium, vanadium and thorium were found to be beneficial additions even in amounts less than 1 at. %.

Compatibility

In the earlier nuclear reactors, the fuel was canned in aluminium, a material which reacts with uranium at temperatures as low as 200°C forming intermetallic compounds. The aluminium/uranium interaction can be effectively prevented by the use of inert interlayers which present a physical barrier to the inter-diffusion of uranium and aluminium. Failure by a rather different mechanism can occur when materials which are based upon iron or nickel are used in contact with uranium. These metals form eutectics with uranium, as do chromium and manganese, the melting points of these eutectics being 815, 790, 860 and 745°C respectively. At temperatures below those at which the eutectics can form, for example 550-600°C for stainless steel, deterioration of the mechanical and physical

TABLE 8

Comparison of Creep Strength at 400°C 3 tons/sq in of Composition—Adjusted Mg-reduced and Ca-reduced Uranium in the Grain Refined Conditions[8]

Metal type	Heat treatment	Av. grain dia. (mm)	Total time (hours)	Total creep strain (%)	Minimum creep rate ($hr^{-1}, \times 10^4$)
Mg-reduced	Traverse quenched, alpha annealed	0.25	1,973	0.5058	2.10
Mg-reduced	Traverse quenched, alpha annealed	0.30	1,684	0.4230	1.82
Mg-reduced	Traverse quenched, alpha annealed	0.30	1,710	0.3930	1.75
Mg-reduced	Traverse quenched, alpha annealed	0.50	1,773	0.3350	1.27
Ca-reduced	Traverse quenched, alpha annealed	0.32	1,637	0.3780	1.76
Ca-reduced	Traverse quenched, alpha annealed	0.35	1,830	0.3240	1.30

properties can still occur by inter-diffusion. Where high uranium surface temperatures are used, the excellent compatibility of the refractory metals such as tungsten, tantalum and niobium are of value (see Table 10). Compatibility results for two solids in contact are highly dependent on the surface conditions of the material. In the data sheets the lowest reported temperature for the onset of incompatibility has been quoted; the present tendency is for uranium/can surfaces to be kept as free from oxide as possible to reduce the temperature drop at the interface.

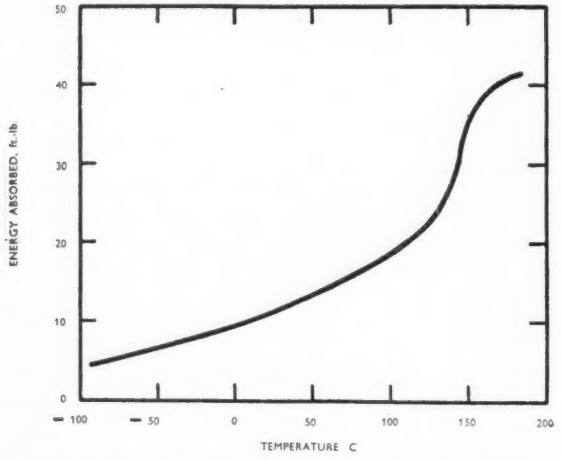

Fig. 7.—Effect of temperature on Charpy notch impact energy of uranium, hot rolled at 550°C and water-quenched[2].

Uranium is relatively reactive with most of the possible coolants. Generally however the can prevents the fuel and coolant being in direct contact and in these cases it is only necessary that catastrophic reaction does not occur as a result of a can failure. Hydrogen forms a special case since it diffuses rapidly through all the common canning materials and it can form a hydride with the uranium at temperatures up to 500°C under moderate pressures. Hydride formation is accompanied by swelling which can produce distortion and splitting of the cans (Fig. 10) with the risk that finely-divided hydride could be dispersed by the coolant and contaminate the core. Uranium hydride is also extremely pyrophoric on exposure to air which would make handling of the defective elements difficult.

Uranium hydride also plays a part in the rapid reaction of uranium with steam or high temperature water (i.e., water heated to 200-300°C but prevented from boiling by application of external pressure). Nascent hydrogen released by the reaction between uranium and water is absorbed by the metal and the expansion which accompanies hydride formation leads to breaking of any protective surface film and eventually to cracking of the metal. The increased surface area resulting from this cracking produces an accelerated and even catastrophic reaction. At 280°C after only 6½ hours, uranium samples suspended in the vapour phase were completely oxidized and those in liquid water were severely attacked showing 37% loss in weight corresponding to 120 mg/cm²-h. Considerable improvement in corrosion resistance has been reported for uranium alloys in which the gamma-phase is retained in a metastable condition on rapid cooling, especially where these are given a subsequent mild heat treatment. Such alloys are those containing more than 7 wt.% of molybdenum and niobium (Fig. 11). The results at low alloy additions are somewhat variable probably because of variation in structure between different samples, and consistent reduction of the corrosion rates is only found with molybdenum and niobium additions of more than 10 wt.%. Another alloy reported to have high resistance to corrosion by high temperature water (Fig. 11) is uranium containing sufficient silicon (3.8 wt.%) to form the intermetallic compound U_3Si. The alloy must be essentially the pure compound to obtain adequate corrosion resistance, and there is some possibility of its deterioration under irradiation by formation of free uranium.

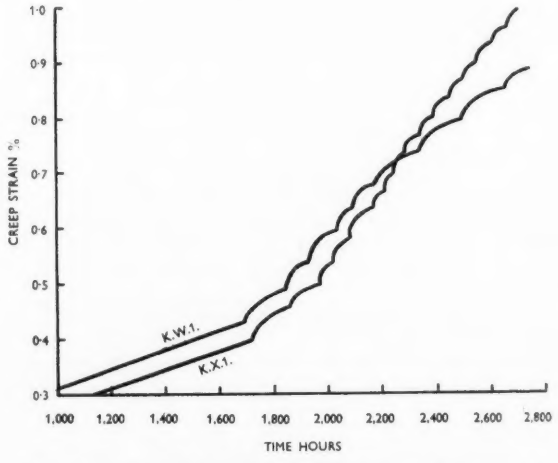

Fig. 8.—Effect of large thermal and load cycling on the creep behaviour of uranium[8] Mg-reduced composition-adjusted uranium, 400°C 3 ton/in². Large thermal cycles together with unload/load cycle.

Uranium also shows a very rapid reaction with air at temperatures above 350°C. An extrapolated penetration rate of 1½ mm/h at 600°C has been reported and under these conditions a burst cartridge would involve a considerable hazard of fire and contamination of the core by loose or evaporated active particles. This problem is less serious with CO_2 as the cooling gas; as will be seen from the values given in the data sheets, relatively low penetration rates are found even at 600°C.

Fabrication

In this country the majority of fuel elements have made use of machined and heat-treated bars of cast uranium. Vacuum H.F. furnaces with graphite crucibles and moulds are the common practice for uranium-rich alloys. To avoid excessive carbon pick-up, alloys of high melting point may require uranium oxide or beryllia crucibles, or these alloys can be arc-melted. In fuel element designs involving thin rods, plates or more complex sections some form of mechanical working may be a more suitable production process than casting.

All the methods commonly employed for other engineering materials can be applied to uranium, but the only ones

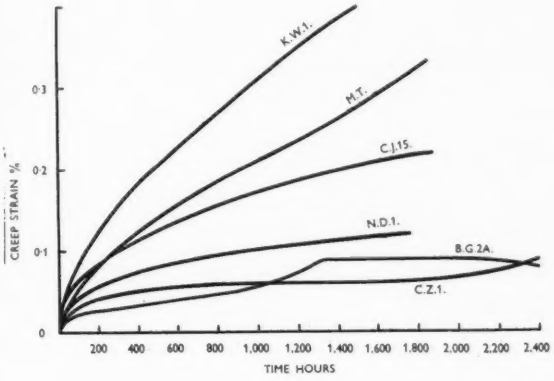

Fig. 9.—Variation of the creep of uranium at 400°C 3 tons/in² with the fabrication history [8].

K.W.1. Mg-reduced traverse β-quenched α-annealed.
M.T. Ca-reduced traverse β-quenched α-annealed.
C.J.15. As-cast Mg-reduced.
N.D.1. Sintered.
B.G.2.A. Remelt Ca-reduced.
C.Z.1. As-cast Ca-reduced.

so far used to any practical extent are rolling and extrusion. Rolling is usually carried out within the range 400-660°C to take advantage of the decrease in hardness and increase in ductility with increase of temperature within the alpha range. Conventional steel-type rolling mills are satisfactory for producing bar within this temperature range, round passes being preferred to oval and gothic passes because

Fig. 10.—Stainless steel canned uranium specimen which burst during heating up from room temperature to 500°C [8].

they reduce the oxidation and the risk of cracking. Rolling is not generally practised at temperatures in the range 660-770°C because the forces required to hot work the relatively hard and brittle beta phase are from 2 to 3 times as great as at 650°C. Above 770°C in the gamma phase region, there is ample ductility but the material is so soft that it becomes almost impossible to handle a long rod as it emerges from the rolls. Where sheet or strip is required as the final product it is often convenient to start operation by enclosing the uranium in a less readily oxidizable metal, for example nickel. A graphite or other barrier film must be provided between the uranium and the nickel to prevent interaction. After rolling to about 0.05 in. the uranium can be removed from its protective sheath and finished by pack or cold rolling. Foil only 0.0005 in. thick has been produced by such a process.

Extrusion is usually carried out at temperatures above 770°C because of the lower loads required to deform the gamma phase; bending of the product can be avoided by extruding vertically downwards. The main difficulty is finding a suitable material for the dies since uranium reacts at these temperatures with iron, cobalt and nickel. A thick graphite separating layer has been used satisfactorily in France but the most satisfactory material so far used has been stellite. Because of these difficulties some extrusion has been done at temperatures of 500 to 600°C.

Forging and swaging can also be done in the temperature range 500 to 660°C whereas hot pressing has been performed in the gamma phase range. Cold working processes such as rolling, drawing, swaging and cupping have also been developed; annealing to remove residual work-hardening after such processes can be done at temperatures of about 475°C. All of the processes mentioned can also

TABLE 9

The Tensile Creep Properties of Some Binary Alloys of Uranium at 500°C 2 tons/sq in [8]

Nominal composition (atomic %)	Metallurgical condition	Average grain dia. (mm)	Time in hours for specified percentage creep strain					Minimum secondary creep rate (in/in-hr)
			0.1	0.2	0.5	1.0	2.0	
U–½ Ti	As cast	0.83	>1,000	—	—	—	—	$<0.2\times10^{-6}$
U–2 V	As cast	0.10	500	1,000	—	—	—	0.2×10^{-6}
U–½ Th	As cast	1.0	100	—	—	—	—	0.2×10^{-6}
U–1 Th	As cast	—	20	250	—	—	—	0.4×10^{-6}
	beta-quenched	1.3	25	200	—	—	—	0.6×10^{-6}
U–4Al	As cast	—	20	80	1,900	—	—	0.8×10^{-6}
	beta-quenched	0.50	—	20	150	550	1,500	12×10^{-6}
U–½ Ge	As cast	0.80	—	20	100	540	—	4×10^{-6}
	beta-quenched	0.2	—	—	15	40	110	135×10^{-6}
U–2 Ge	As cast	0.80	—	15	86	320	1,100	5×10^{-6}
	beta-quenched	0.40	—	10	60	—	—	38×10^{-6}
U–2 Fe	As cast	1.06	—	20	40	120	580	30×10^{-6}
	beta-quenched	0.3	—	5	10	20	60	700×10^{-6}
Mg–Red. uranium	beta-quenched alpha annealed	0.33	10	31	95	195	380	54×10^{-6}

be used for the alloys of uranium although difficulties may arise due to the presence of hard and brittle compounds; for large alloying additions gamma-phase extrusion or swaging appears most satisfactory.

Powder metallurgy routes are also possible although uranium only sinters readily at temperatures above 80% of the melting point in contrast with nickel and other metals which densify at 50% of their melting temperatures. Very fine powder (less than 300 mesh) can be prepared by decomposition of the hydrides and when this is cold pressed at 70 ton/in^2 and sintered in vacuum at 1,125°C, 94% theoretical densities can be achieved. Hot pressing in

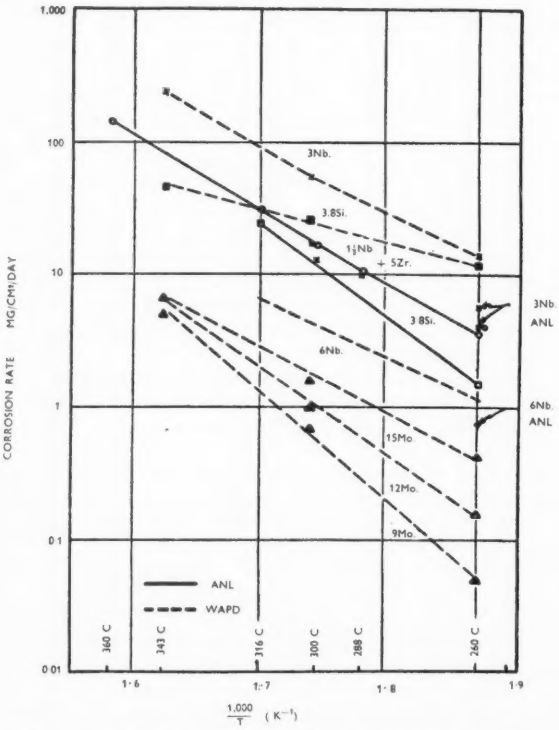

Fig. 11.—Corrosion of uranium-base alloys in distilled water [4].

vacuum at about 20 ton/in^2 and a temperature of 600°C gives material of slightly higher density and with a very much finer randomly oriented grain structure. An extrusion process has also been developed.

In the machining of uranium there are two basic problems; the metal work hardens rapidly and it readily oxidizes. As a result of the pronounced work hardening, heavy cuts (a minimum of 0.025 in.) are recommended, especially when parting off. When making such cuts, the power requirements may be at least 50% in excess of the normal drive for similar operations on steel. Carbide-tipped tools with mineral oil or water-soluble oil coolants are satisfactory. The fine turnings may ignite especially if wet and the accumulation of metal chips should be kept to a minimum. Where it is advantageous from criticality or processing requirements, uranium can be machined dry in an argon atmosphere using refrigerated argon as the coolant.

The difficulties of welding and brazing uranium are associated with its extreme reactivity at high temperatures. Some success has been achieved with pressure welding in an argon atmosphere using high-frequency heating. Pressures of 5-10 ton/in^2 at temperatures in the alpha phase gave welds with tensile strengths about 80% of the parent metal.

TABLE 10

Temperature at which Cans fabricated from Different Materials fail when in Contact with Uranium[3]

Metal	Temperature at which 0.020 in. can is penetrated in 1 min (°C)
Tungsten	1,500
Tantalum	1,460
Niobium	1,430
Zirconium	1,380
Titanium	1,350
Molybdenum	1,280
Tantalum-coated Nickel	1,130
Vanadium	1,130
Chromium	~1,000
Nickel	850 to 950
Stainless Steel	
Nimonic	
Inconel	

The Effect of Reactor Conditions

The changes which occur in a fuel element during its service can be due to two processes; the effect of prolonged exposure to high and varying temperatures and the effect of neutron bombardment and fission processes. One of the possible thermal effects is the change of shape and reduction in density referred to earlier due to repeated alpha-beta transformations. Similar but less pronounced changes can occur when material with a preferred orientation is cycled over temperatures in the alpha range.

Apart from these thermal effects, the anisotropic nature of alpha uranium also produces dimensional effects under neutron irradiation. A single crystal of uranium on irradiation at relatively low temperatures will distort so that one particular direction (the 010) always lengthens, whereas the other principal directions perpendicular to this shorten or remain unchanged. As a result, directional growth under irradiation will occur in uranium bar in which the various crystals tend to have similar orientations, as is the case in alpha-rolled uranium. In cast uranium where the

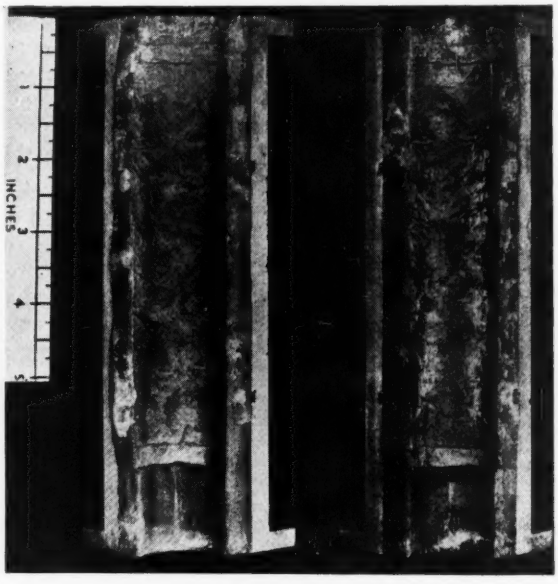

Fig. 12.—Wrinkling on irradiation as shown by lead replicas [22].

constituent grains are randomly orientated, such macroscopic changes in dimensions do not occur, but if the grain size is large the surface grains tend to deform individually in different directions. This produces a roughening of the surface called wrinkling (Fig. 12). To reduce this effect, uranium for fuel elements should have a fine grain structure, its average grain size being about 0.3 mm. A convenient production process known as traverse quenching consists of passing the bar first through an H.F. heating coil and then through a water spray.

Another effect which results from the anisotropic growth of uranium crystals under irradiation is known as irradiation creep. As the individual crystals in a bar of random orientation try to grow in different directions they produce internal stresses which can be additive to any external applied stress. In a similar way to that described earlier when considering the effect of thermal cycling on creep, these stresses can increase the rate of creep at a particular applied stress level. The magnitude of this effect was calculated by Cottrell[1] and experimental evidence has confirmed his predictions. Since the irradiation distortion of uranium crystals is very temperature dependent, being a maximum at 200°C and decreasing with increase of temperature to zero about 400°C, both irradiation creep and wrinkling would be expected to show similar temperature dependence. Wrinkling measurements have in fact shown maximum values for irradiations at temperatures of about 200°C (Table 11).

TABLE 11

The Effect of Degree and Temperature of Irradiation on Wrinkling of As-cast Uranium[19]

Temperature range in which Irradiated (°C)	Average Wrinkling Parameter after irradiations (in MWD/T) shown below									
	100 to 199	200 to 299	300 to 399	400 to 499	500 to 599	600 to 699	700 to 799	800 to 899	900 to 999	>1,000
50– 99	3	4½	4½							
100–149	3	6	5½	8	4					
150–199		4½	5½	7	6	9½	10½	10		
200–249			4	5	5	4½	5	—	7	6
250–299					4	4	4	4½	3	5½
300–349					2	4	—	3½	8	7

At higher temperatures uranium suffers irradiation damage by a different mechanism known as swelling. The uranium atom splits on fission into two or more atoms which occupy a somewhat larger volume than the uranium from which they were formed. Part of the fission products consist of the inert gases argon and krypton; it can be shown that one cubic centimetre of uranium irradiated to 1% burn-up will produce 4.73 cm^3 of stable inert gas at normal temperature and pressure. These gas atoms are produced on the lattice of the uranium crystal but they are virtually insoluble.

They diffuse through the lattice until they find a point at which they can escape, for example a pore or inclusion, and a gas bubble is formed within the metal. It is, however, very difficult for such escaped gas atoms to be reabsorbed on to the uranium lattice with the results that with continued irradiation the pressure within these gas bubbles increases. This internal pressure can cause deformation of the uranium surrounding the bubbles which thus increase in size and a decrease in average density with increase in overall dimension occurs (Fig. 13).

The amount of this decrease of density appears to increase with both increase of irradiation and temperature; it also shows appreciable variation from one material to another. Typical values are shown in the data sheet; the lowest swelling rate has been found for uranium—14 wt.% molybdenum alloys which showed a 3% decrease in density per 1% burn up at 800°C. This material has an isotropic structure and is considerably stronger than unalloyed uranium at high temperatures.

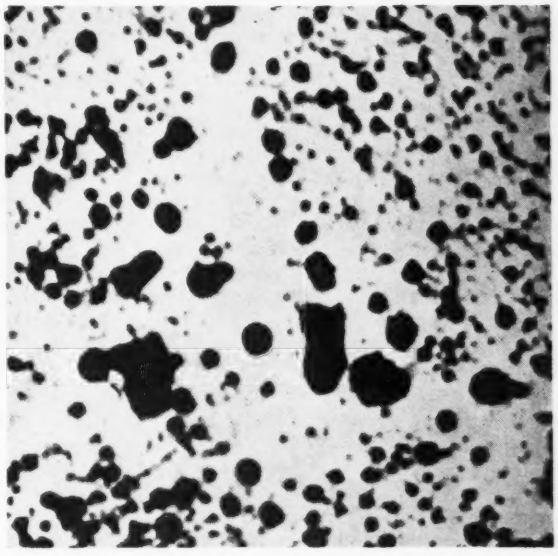

Fig. 13.—Section of a specimen after irradiation to about 0.1% burn up. The measured density decrease was about 13%[22].

Many of the properties of uranium are changed by irradiation. A sample irradiated at low temperatures shows heavy deformation markings and other evidence of cold work. The hardness of uranium at first decreases slightly on irradiation at 200°C, but further irradiation causes an increase in hardness in annealed material (Table 12). The results may be regarded as indicating two competing processes; hardening by displaced atoms and fission products and softening by an annealing process. Increases in tensile yield strength and marked decreases of ductility with quite small irradiations have also been reported.

TABLE 12

Effect of Irradiation on the Hardness Properties of Rolled and Annealed Uranium Sheet[11] (P. E. Madsen)

Specimen	Irradiation		Meyer Index n	Ultimate hardness PU	Brinell hardness (30 kg load)
	Time (h)	Dose (neutrons/sq cm)			
Alpha rolled sheets	0	0	2.407	605.7	369
	14	5.0×10^{15}	2.318	474.6	326
	144	5.2×10^{16}	2.338	518.7	346
	443	1.6×10^{17}	2.272	458.5	331
	1,484	5.3×10^{17}	2.292	500.0	343
Above sheet annealed ½ h 635°C	0	0	2.368	427.8	284
	14	5.0×10^{15}	2.381	408.4	271
	144	5.2×10^{16}	2.417	446.3	282
	443	1.6×10^{17}	2.348	413.8	281
	1,484	5.3×10^{17}	2.218	382.2	296

Irradiation also produces changes in the physical and chemical properties of uranium. In a low zirconium alloy of uranium a decrease of about 5% in thermal conductivity was produced by a burn-up of 0.1% of total atoms. The aqueous corrosion resistance of uranium alloys containing 3 wt.% niobium or 5 wt.% zirconium has been shown to be adversely affected by irradiation. Alloys containing about

9 wt.% molybdenum, however, show somewhat improved corrosion resistance, possibly because the gamma phase is stabilized in these alloys by irradiation.

Finally, irradiation affects the nuclear properties of the fuel because of the neutron absorption of the fission products and the formation of plutonium, together with the decrease in the number of fissile atoms present.

The effects of service conditions on uranium are thus seen to be complex. Apart from purely thermal effects, neutron bombardment produces displaced atoms and vacancies; around each fission event a volume of metal is subject to a high temperature and stress; the fission products in themselves can strain the lattice and produce swelling. In view of these complexities and the difficulties of accurate determinations on irradiated specimens, it is not surprising that the quantitative data are limited and sometimes contradictory.

General Remarks

In the preceding paragraphs and the accompanying data sheets the known properties of uranium have been summarized. It has been indicated that many of the difficulties that arise in its use as a nuclear fuel stem from the anisotropic nature of alpha uranium. Growth of rolled bars, wrinkling and increased creep rates under irradiation and thermal cycling all arise from this factor and the desirability of fine-grained, randomly-orientated material, especially at relatively low irradiation temperatures, has been emphasized. With the use of higher irradiation temperatures, swelling becomes an important problem and high creep strength materials may be helpful. Some indication of how the strength and corrosion resistance of uranium can be increased by alloying has been indicated in the text. However, alloy additions frequently bring problems apart from fabrication and neutron-absorption difficulties. For example it is necessary to process the element after irradiation to remove fission products and plutonium. If a chemical process is used the rate of dissolution may be decreased by alloying elements such as molybdenum. Vanadium and chromium can increase the corrosion rate of stainless steel chemical processing vessels. Precipitation from the solution and limitation of the amount of evaporation which can be done in the concentration stage also are factors affecting the use of aluminium, niobium, chromium and molybdenum alloys. These difficulties are of course capable of solution provided that the advantages obtained by alloying are sufficiently great. It must be expected that the interest in the use of alloy additions and of the refractory uranium compounds such as oxides and carbides will increase in order to achieve higher gas temperatures and longer irradiation times with resulting reduction of the cost of the generated electrical power.

Acknowledgments

Many of the results quoted in this article have not previously been published in the open literature and arise from work done at the various laboratories of the Research and Development Section of the United Kingdom Atomic Energy Authority (Industrial Group) and at the Atomic Energy Research Establishment, Harwell. Acknowledgments are made to the colleagues in these Establishments whose work has been included, particularly as it has not been possible to include detailed reference to their individual papers. Thanks are also due to Sir Christopher Hinton, K.B.E., F.R.S., Managing Director, and to Mr. L. Rotherham, Director of Research and Development, of the United Kingdom Atomic Energy Authority (Industrial Group) for permission to publish this article.

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L'Uranium et ses Alliages
Résumé

Des feuilles de données de valeurs choisies pour les propriétés physiques, mécaniques, chimiques et nucléaires de l'uranium et de ses alliages sont présentées. Le comportement directionnel de l'uranium alpha y est décrit et on y discute les effets résultant des propriétés ci-dessus, particulièrement sur les changements dimensionnels et l'augmentation du taux de fluage sur le cyclage thermique et l'irradiation. D'autres effets possibles des conditions de réacteur sont les changements de densité dus à la transformation de phase et au gonflement sous la pression intérieure des gaz du produit de fission.

Le degré de ce gonflement pourrait dépendre de l'intensité du fluage et les valeurs de l'intensité de fluage sont données en détail. La compatibilité de l'uranium avec les matériaux de mise en boîte et les réfrigérants est aussi discutée et les effets de l'alliage sur toutes ces propriétés sont indiquées.

Uran und seine Legierungen
Zusammenfassung

Der Artikel enthält Aufstellungen über ausgesuchte Werte der physikalischen, chemischen und Kerneigenschaften von Uran und Uranlegierungen. Das Richtungsverhalten von Alpha-Uran wird beschrieben und dessen Einfluss auf obige Eigenschaften, insbesondere auf dimensionale Aenderungen und erhöhte Kriechgeschwindigkeit bei thermalen Kreisprozessen und bei Bestrahlung besprochen. Weitere mögliche Wirkungen der Verhältnisse im Reaktor sind Aenderungen der Dichte infolge von Phasenänderung und Anschwellen unter dem Innendruck der Gase der Zerfallsprodukte. Das Ausmass dieses Schwellens kann von der Kriechfestigkeit abhängen, und es sind Kriechfestigkeitswerte im einzelnen angegeben. Die Verträglichkeit des Urans mit "Canning"-Materialien und Kühlmitteln wird ebenfalls besprochen und die Auswirkungen des Legierens auf alle diese Eigenschaften angedeutet.

Uranio y sus Aleaciones
Resumen

Las hojas de datos de valores seleccionados para las propiedades fisicas, mecánicas, químicas y nucleares del uranio y sus aleaciones se presentan. Se discuten el compartamiento direccional de alfa-uranio, así como también los efectos resultantes de dichas propiedades, especialmente sobre los cambios dimensionales y la razón aumentada de deslizamiento en relación al ciclaje térmico y la irradiación. Los otros posibles efectos de las condiciones del reactor son los cambios de densidad debido a la transformación de fase y al hinchamiento bajo la presión interna de los gases de productos de fisión. La magnitud de este hinchamiento puede depender de la fuerza de deslizamiento y se ofrecen en detalle los valores de dicha fuerza. La compatibilidad del uranio con materiales de envasamiento y con los refrigerantes también se discute, y se indican los efectos de "aleacionado" sobre todas estas propiedades.

Nuclear Engineering
DATA SHEET
No. 1. Uranium

A. PHYSICAL PROPERTIES

(i) DENSITY

Values calculated from X-ray data[2]

Phase	Temperature (°C)	Vol. per Atom (10^{-24} cm³)	Density (g/cm³)
alpha	25	20.75	19.04
alpha	200	20.93	18.88
alpha	400	21.17	18.67
alpha	650	21.57	18.33
beta	720	21.82	18.11
gamma	805	21.98	18.06

High purity material directionally solidified; density at 25°C 19.05 ± 0.02 g/cm³
Wrought material .. .. 18.7 — 19.08 g/cm³

(ii) TRANSFORMATION TEMPERATURES (°C)[12]

Material	Alpha to beta	Beta to gamma	Melting point	Boiling point	Recrystallization Temperature
Pure Uranium	662	769	1129	3818	~ 475°C (dependent on degree of cold work and impurity content)
U- ½ at % Cr	645-655	755-760	1110-1115	—	—
U- 2 at % V	652	745-765	1115-1125	—	—
U- 4 at % Al	655	755	1102-1110	—	—
U- 2 at % Fe	675	770	815-1100	—	—
U- 2 at % Mo	660	575-735	1110-1120	—	—
U-28 at % Mo	not formed	572-598	1200-1410	—	—

Where 2 values are quoted, the lower indicates the lowest temperature at which the high temperature phase is found under equilibrium conditions; the higher is the temperature for complete transformation.

The alpha phase is orthorhombic with 4 atoms per unit cell.[2]

Lattice constants at 25°C $a_0 = 2.8541 \pm 0.0003$ Å

$b_0 = 5.8692 \pm 0.0015$ Å

$c_0 = 4.9563 \pm 0.0004$ Å

The beta phase is tetragonal with 30 atoms/unit cell

Lattice constants at 720°C $a_0 = 10.759 \pm 0.001$ Å

$c_0 = 5.656 \pm 0.001$ Å

The gamma phase is body-centred cubic, 2 atoms/unit cell

Lattice constants at 800°C $a_0 = 3.49$ Å

(iii) VAPOUR PRESSURE[3]

From 1630 to 1970°K

$$\log P\,(\text{mm Hg}) = -\frac{2330 \pm 21}{\text{absolute temp. (°K)}} + (8.583 \pm 0.011)$$

(iv) SPECIFIC HEAT[11]

Temperature (°C)	Specific Heat (cal/g °C)
100	0.0278
200	0.0296
300	0.0324
400	0.0353
500	0.0392
600	0.0437
660	0.0466
680	0.0394
700	0.0396
770	0.0397
790	0.0340
800	0.0340

(v) OTHER THERMAL CONSTANT

Entropy at 25°C	11.99 ± 0.02 cal/c
Enthalpy at 25°C	1521.4 ± 1.6 cal/c
Heat capacity at 25°C	6.612 ± 0.007 cal/c
Heat of sublimation at 0°K	116.6 ± 0.1 k

Phase change	Latent heat of transformation (kcal/mole)	
alpha-beta	0.69	
beta-gamma	1.14	
gamma-liquid	4.7	
liquid-vapour	106.7 ± 1	

(vi) THERMAL EXPANSION[2,6]

For coefficients of thermal expansion of an alpha-uranium sin
directions, refer to Figure 1. As a result of this anisotrop
variation in the results on different polycrystalline samples
fabrication histories (see Table 1 in text). Similar anisotro
phase :—

beta-Uranium, direction a. linear thermal expansion (20 — 72
beta-Uranium, direction c. linear thermal expansion (20 — 720

Mean values for a randomly-orientated polycr

Temperature	Phase	Mean linea
25—100	alpha	1
25—250	alpha	1
25—400	alpha	1
25—550	alpha	1
25—625	alpha	1
20—720	beta	1
650—750	beta	2
20—800	gamma	1
775—800	gamma	2
Mg-reduced U (beta-quenched and alpha-annealed)	alpha	$L_t = L_0$ (1 7.9
U-½ a/o C. Isothermally treated by quenching from 731°C to 550°C and holding 1 hour	alpha	$L_t = L_0$ (1 1.0

(vii) MAGNETIC PROPERTIES[1]

Susceptibility (e.m.u./g)	Temp (
1.720	
1.891	6
2.017	throughout b
2.074	9

(viii) THERMOELECTRIC FORCE[14]

Temperature (°C)	Thermoelectric Fo against platin
50	0.52— 0.5
100	1.15— 1.2
250	3.75— 4.1
500	10.21—11.1
600	13.37—14.7
700	16.81—18.5
800	20.59—22.5
900	24.75—26.5

RMAL CONSTANTS [2, 11]

11.99 ± 0.02 cal/deg. mole.
1521.4 ± 1.6 cal/deg. mole.
6.612 ± 0.007 cal/deg. mole.
°K 116.6 ± 0.1 kcal/mole.

nt heat of nsformation cal/mole)	Entropy of transformation (cal/deg. mole)
0.68	0.72
1.14	1.08
4.7	—
106.7 ± 1	—

AL EXPANSION[2, 8]

of an alpha-uranium single crystal in different result of this anisotropy there is considerable polycrystalline samples especially of different ext). Similar anisotropy is shown in the beta

rmal expansion (20—720°C): 23×10^{-6} per °C.
rmal expansion (20—720°C): 4.6×10^{-6} per °C.

nly-orientated polycrystalline bar

Phase	Mean linear thermal expansion coefficient (per °C)
alpha	13.2×10^{-6}
alpha	15.5×10^{-6}
alpha	17.0×10^{-6}
alpha	19.0×10^{-6}
alpha	19.8×10^{-6}
beta	13.8×10^{-6}
beta	28.6×10^{-6}
gamma	18×10^{-6}
gamma	22.6×10^{-6}
alpha	$L_t = L_0 (1 + 1.317 \times 10^{-5} t + 7.90 \times 10^{-9} t^2)$
alpha	$L_t = L_0 (1 + 1.19 \times 10^{-5} t + 1.03 \times 10^{-8} t^2)$

NETIC PROPERTIES[13]

	Temperature (°C)
	14
	660
	throughout beta-phase range
	913

OELECTRIC FORCE[14]

Thermoelectric Force mV against platinum
0.52— 0.58
1.15— 1.27
3.75— 4.10
10.21—11.18
13.37—14.72
16.81—18.57
20.59—22.51
24.75—26.58

(ix) THERMAL CONDUCTIVITY[8]

Temperature (°C)	Thermal Conductivity (cal cm⁻¹ sec⁻¹ °C⁻¹)			
	Cast Uranium	Cast Uranium	U—$\frac{1}{4}$ a/o chromium	U—12.4 at a/o Mo
0	0.062₉	—	—	—
100	0.066₈	0.0695	0.0646	—
200	0.070₆	0.0744	0.0693	0.055
300	0.074₃	0.0793	0.0740	—
400	0.078₃	0.0842	0.0786	0.061 (380°C)
500	0.082₂	0.0891	0.0833	0 068 (487°C)
600	0.086₁	0.0940	0.0856 (550°C)	—
650	0.088₁	0.0964	—	—
680	0.088₂	—	—	—
700	0.089₁	—	—	—
720	0.089₉	—	—	—
740	0.090₇	—	—	—
760	0.091₅	—	—	—

EFFECT OF ALLOY ADDITIONS [15]

Material	Condition	Thermal Conductivity at 70°C (±0.003) (cal cm⁻¹ sec⁻¹ °C⁻¹)
High Purity U	Q 1000°C	0.0710
High Purity U	Q 900°C	0.0718
Hot pressed U	from UH_3 powder	0.0649
U—0.03 wt. % C	as rolled	0.0702
U—0.08 wt. % C	as rolled	0.0702
U—1.1 wt. % Zr	as rolled	0.0595
U—2.2 wt. % Zr	as rolled	0.0571
U—0.1 wt. % Cr	as rolled	0.0645
U—0.5 wt. % Cr	as rolled	0.0663

(x) ELECTRICAL RESISTIVITY[8]

Values ranging from 25.0 to 41.0 microhm cm have been reported for the room temperature resistivity of uranium, depending on purity and condition of the material.

Temperature (°C)	Resistivity (microhm cm)	
	Sintered U (18.64 density)	Cast U
0	32.2	—
100	38.8	37.3
200	45.3	43.8
300	50.5	49.4
400	55.0	53.4
500	58.2	56.5
600	59.8	58.4
650	57.4	58.9
700	57.8	56.8
750	58.3	—
800	56.9	—
900	58.7	—

B. MECHANICAL PROPERTIES

(i) ELASTIC PROPERTIES OF URANIUM

Material and nature of test[3]	Young's Modulus lb/in²	Shear Modulus lb/in²	Bulk Modulus lb/in²	Poisson's Ratio
Static Compression Average values	25.5×10^6	10.6×10^6	14.2×10^6	0.20
Dynamic				
Swaged	29.1×10^6	11.9×10^6	—	0.20
Gamma extruded	29.3×10^6	12.0×10^6	—	0.21
Gamma extruded	30.3×10^6	12.1×10^6	—	0.25
as-cast	29.5×10^6	12.1×10^6	—	0.22
as-cast	30.0×10^6	12.1×10^6	—	0.25
average, dynamic	29.7×10^6	12.1×10^6	—	0.23

Temperature coefficient for Young's Modulus (see also Fig. 2)

$$\frac{1}{E} \cdot \frac{dE}{dT} = -5.0 \times 10^{-4} \text{ per } ^\circ\text{C}.$$

Temperature T (°C)	Ratio of Modulus[10] at Temp. T to 20°C value
20	1
220	0.9
380	0.8
500	0.7
600	0.6
630	0.54
690	0.54

(ii) R.T. COMPRESSIVE STRENGTH OF URANIUM[3]

	Limit of Proportionality (Ton/sq in)	0.1% Yield Strength (Ton/sq in)	0.2% Yield Strength (Ton/sq in)
Average values	1.3	12.1	14.8

(iii) TENSILE PROPERTIES[3]

For effect of alloy additions and fabrication history, see Tables 2—6 and Figure 6 in text.

Material	Test Temperature (°C)	L of P (ton/sq in)	0.05% Proof Stress (ton/sq in)	U.T.S. (ton/sq in)	Elongation % on $4\sqrt{Ag}$ 1	E (psi) × 10^{-6}
As-Cast Ca reduced U : 550 ppm C. 300 ppm Fe. 750 ppm Al. 150 ppm Si.	200	2.5	10.4	28.7	10	19.8
	300	2.7	10.6	24.3	18	20.0
	400	3.5	10.1	19.5	18	20.4
	500	1.8	7.5	13.7	24	14.3
	600	1.4	5.1	8.5	22	11.4
	700	1.1	3.6	10.0	24	9.4
As above, beta-quenched and alpha-annealed	400	3.6	11.1	26.7	20	22.3
As-cast Mg-reduced U : 850 ppm C. 90 ppm Fe. 35 ppm Al. 25 ppm Si.	200	2.2	7.6	20.2	24	24.2
	300	2.5	7.2	15.3	30	20.4
	350	3.6	6.4	11.2	27	20.4
	400	2.2	4.9	7.1	28	18.3
	450	2.4	5.3	9.5	19	16.1
	600	0.9	1.9	3.7	42	12.7
	700	0.8	1.8	5.8	13	9.0
As-cast Mg-reduced U : 1,000 ppm C. 495 ppm Fe. 50 ppm Al. 20 ppm Si.	300	3.6	8.9	16.3	20	20.4
	350	2.6	7.3	13.3	21	20.8
	600	1.0	2.6	4.7	31	11.6

(iv) NOTCH IMPACT STRENGTH OF URANIUM[3]

(see also Figure 7)

Test Temperature (°C)	Charpy Energy Value (ft lb)				
	Alpha-rolled	As-cast	Beta-quenched	Beta-quenched and Alpha-annealed	Gamma-quenched
−73	6	8	5	6	8
−60	8	10	6	7	8
−45	10	12	7	7	10
−32	10	12	7	8	11
0	12	12	8	9	13
10	14	13	9	10	16
24	14	14	11	12	16
38	15	15	12	14	17
65	18	17	15	20	22
93	25	23	18	27	28
150	32	27	29	52	50

Mechanical Properties—cont.

(v) HARDNESS [6-11]

Temperature (°C)	Brinell Hardness, 0.249 in dia. Tungsten Ball, 400 kg. load, 30 sec				
	As-cast U 500 ppm C	Hot-pressed compact, 3000 ppm C	U –0.4 w/o Mo 800 ppm C, as-cast	U –1.2 w/o Mo 800 ppm C, as-cast	U –4.9 w/o Mo 750 ppm C, Ann. 1000°C, 10 hr slow cool
–72	207	—	—	—	—
– 4	196	—	—	—	—
RT	187	232	280	267	367
100	150	189	253	235	340
200	125	155	219	190	305
300	109	110	203	185	272
400	79	74	172	154	238
500	52	44	128	115	163
600	28	—	60	49	32
650	20	—	47	16	—
658β	38	—	—	—	—
670	36	—	—	—	—
700	31	—	25	12	17

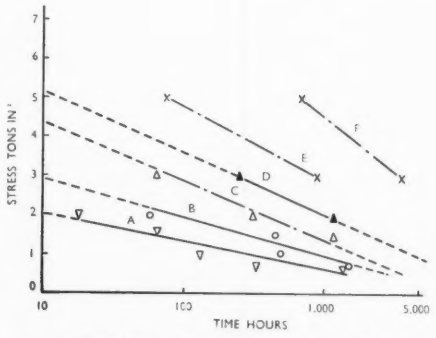

Fig. A.—Stress-log time relationships for re-melted calcium-reduced uranium at 400° 450° and 500°C (8).

(vi) CREEP[8]

Material	Stress (t.s.i.)	Time (h) for specified percentage creep strain						Duration of test (h)	Total creep strain %
		0.05	0.10	0.20	0.50	1.00	2.00		
200°C									
C	10.0							1,140	0.034
M	10.0	67	160	225	360			460	820
300°C									
C	6.0							4,340	0.040
M	6.0	233						1,430	0.085
C	8.0	3,150						7,200	0.070
M	8.0	4	25	161				350	0.270
400°C									
R	1.0							1,500	0.012
R	2.0	2,900						7,250	0.082
M	2.0							1,480	0.048
R	3.0	862	3,504					6,000	0.123
C	3.0	450						3,100	0.082
M	3.0	55	300	1,150				1,900	0.213
CBQ ..	3.0	40	170					530	0.189
MAQA ..	3.0	27.5	103	404				812	0.227
R	5.0	73	649					2,577	0.190
C	5.0	29	260	3,474				6,650	0.254
M	5.0	22	142	407				1,300	0.365
CBQ ..	5.0	16	55	145				257	0.289
C	6.0	25	145	700				2,869	0.488
M	6.0	17	48	175	895	1,890		3,284	1.750
C	7.0	15	55	265				1,826	0.498
M	7.0	2	14	32	160	350		592	1.880
450°C									
R	1.5	1,161						3,350	0.060
R	2.0	299	1,166					2,933	0.176
R	3.0	75	260	1,303				1,665	0.260
500°C									
R	0.5	1,328						4,500	0.070
R	0.75	315	1,530	2,572				4,687	0.049
R	1.0	130	481	1,517	3,645	5,723		6,385	1.605
C	1.0	900	1,970					3,961	0.172
M	1.0	35	140	425	910	1,450	2,160	2,520	2.759
R	1.5	66	450	1,986				2,160	0.217
R	2.0	18	60	230	625			1,984	2.260
C	2.0	60	155	463	1,260	2,115		2,617	1.487
M	2.0	6	12	38	144	365	675	749	2.500
CBQ ..	2.0				5	30	135	214	3.857
600°C									
M	0.25	65	147	275	637	1,108	1,350	1,493	3.018
M	0.50	12	32	68	150	300	620	727	2.368
700°C									
M ..	0.25	38	95	202	446	795	1,490	1,673	2.247
M	0.50	5	12	25	83	209	503	634	2.539

Key to Materials in above Table

Code	Uranium Type	Carbon Content ppm
R	Re-melted Ca-Reduced U (As-Cast)	1480
C	As-Cast Ca-Reduced U	550
CBQ	As-Cast Beta-Quenched	550
M	As-Cast Mg-Reduced	850
MAQA	Mg-Reduced, Composition Adjusted, Beta-Quenched and Alpha-Annealed	—

Stress-Log Time Relationships for Re-melted Ca-Reduced U Fig. A
Stress-Strain Rate Relationships at 400 and 500°C Figs. B & C
Stress Relaxation Data on U–¼% Cr Alloy Fig. D

For other creep data on uranium alloys, see Table 9 in text.

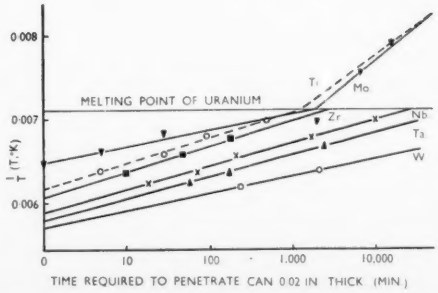

Fig. E.—Compatibility of uranium with refractory metals (9).

C. COMPATIBILITY

(i) WITH OTHER METALS[8]

Metal	Compatibility for Tests ~ 200 h	Temperature (°C)
Aluminium	Incompatible	300
Beryllium	Incompatible	600
Chromium	Compatible	600
Copper	Incompatible	600
Iron	Compatible	500
	Incompatible	600
Molybdenum	Compatible	600
Nickel	Compatible	500
	Incompatible	700
Niobium	Compatible	600
Stainless Steel	Compatible	500
	Some Reaction	550
	Extensive Reaction	700
Tantalum	Compatible	900
Titanium	Compatible	700
	Incompatible	900
Zirconium	Compatible	700
	Incompatible	800

Variation of penetration rate with temperature for refractory metals :

For minimum temperature at which penetration of an 0.020" can occur in minute, see Table 10 in text.

(ii) WITH GASES [11-16]

Temperature (°C)	Penetration Rate (cm/h)			
	Air	Steam	CO_2	Hydrogen
200	7×10^{-5}	5.5×10^{-3}	1.7×10^{-6}	2.7×10^{-1}
250	4.4×10^{-4}	3.1×10^{-2}	2.9×10^{-6}	3.0×10^{-1}
300	1.1×10^{-3}	2.8×10^{-2}	4.3×10^{-6}	1.9×10^{-1}
350	3.7×10^{-3}*	3.5×10^{-2}	5.5×10^{-6}	—
400	1.1×10^{-2}*	3.1×10^{-2}	5.6×10^{-6}	—
450	—	2.0×10^{-2}	1.0×10^{-5}	—
500	—	2.0×10^{-2}	5.7×10^{-5}	—
550	—	—	—	—
600	—	1.8×10^{-2}	—	—

* extrapolated data

The reaction of uranium with hydrogen to form UH_3 is most rapid ($\sim 7.5 \times 10^{-4}$ g atom hydrogen/cm²/min) at 225°C and above this temperature the rate decreases as the decomposition pressure of the hydride approaches the externally applied pressure.

Temperature (°C)	Dissociation Pressure of Uranium Hydride	
	(mm Hg)	(p.s.i.a.)
400	350	6.8
500	2560	49.5
600	11910	230.3

The diffusion coefficient for hydrogen in uranium is :—

Temperature (°C)	Diffusion Coefficient (in²/h)
546	0.0140
593	0.0364
640	0.0125

Uranium also reacts readily with nitrogen although in oxygen-nitrogen mixtures the oxide is formed preferentially.

Temperature (°C)	Increase in wt. (g) of Specimens 2 cm dia. × 2 cm long after 24 h in nitrogen[9]
300	0.0006
400	0.0022
500	0.0074
600	0.0315

(iii) WITH LIQUIDS[2-4-8]

The corrosion rate of uranium in water depends upon the purity of the water and its hydrogen content. In low conductivity distilled water in the presence of air a corrosion rate of 120 mg/cm²/h was found for unalloyed uranium. Corresponding values for uranium alloys are shown in Fig. 11. The variation with temperature of corrosion rate of unalloyed uranium in hydrogenated water is shown in Fig. F.

Uranium is compatible with pure sodium up to at least 600°C ; where the sodium contains oxygen however this reacts with the uranium forming uranium-oxide. The rate of this reaction increases with temperature and oxygen content but quantitative data are not available.

D.

The effect
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The follow

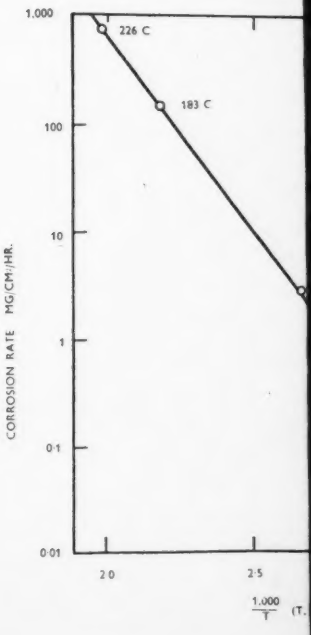
Type of Test
1 mm. Springs
End-loaded fuel element
Horizontal sagging fuel elements

(iii) GROWTH RATE OF A URA

Direction pole	Irradiation Growth Coefficien Irradiated to 0.1
(100)	−
(010)	+
(001)	

(iv) EFFECT OF IRRADIATION O RESISTANCE OF URA

Composition	% Atom Burn-up	(Irradiate
3 Wt. % Nb, Gamma-Quenched	None	No failu weight
	0.1	Disintegr
5 Wt. % – 1.5 Wt. % Nb, Gamma-Quenched.	None	No failur weight
	0.04	Cracking weight



D. EFFECTS OF REACTOR CONDITION

(i) IRRADIATION CREEP [1-10]

The effects of thermal cycling on creep rate and dimensional stability of uranium and its alloys are shown in Figs. 3 and 4.

The following results indicate irradiation effects :—

Type of Test	Average Temp. (°C)	Duration (Weeks)	Specific Power Rating (MW/T)	Burn-up MWD/T	Max. Fibre Stress (psi)	Elastic Deflections per MWD/T
1 mm. Springs	100	14	0.435	42.5	180	0.38
					900	0.49
					2,000	0.66
End-loaded fuel element	100–200	8	0.52	29	280	0.72
Horizontal sagging fuel elements	180 & 250	$10\frac{1}{2}$	0.425	38	70	1.45
	330	$10\frac{1}{2}$	1.05	79	70	1.39

(ii) IRRADIATION SWELLING

(See Fig. G)

(iii) GROWTH RATE OF A URANIUM SINGLE CRYSTAL [17]

Direction pole	Irradiation Growth Coefficient (10^{-6} per ppm Burn-up) Specimen Irradiated to 0.1% Burn-up at 100°C
(100)	-420 ± 20
(010)	$+420 \pm 20$
(001)	0 ± 20

(iv) EFFECT OF IRRADIATION ON AQUEOUS CORROSION RESISTANCE OF URANIUM ALLOYS [18]

Composition	% Atom Burn-up	Corrosion Resistance (Irradiated Specimens were Tested out of Pile)
3 Wt. % Nb, Gamma-Quenched	None	No failure after 2,000 hr. at 260°C. Average weight loss rate, 4.3 mg/cm²day.
	0.1	Disintegrated after 1 hr. at 260°C.
5 Wt. % – 1.5 Wt. % Nb, Gamma-Quenched.	None	No failure after 360 days at 265°C. Average weight loss rate, 2.7 mg/cm²day.
	0.04	Cracking after 63 hr. at 260°C. Average weight loss rate 23 mg/cm²day.

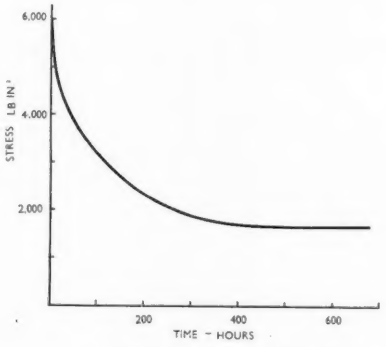


Fig. D.—Stress relaxation of uranium—½% chromium alloy at 375°C (8).

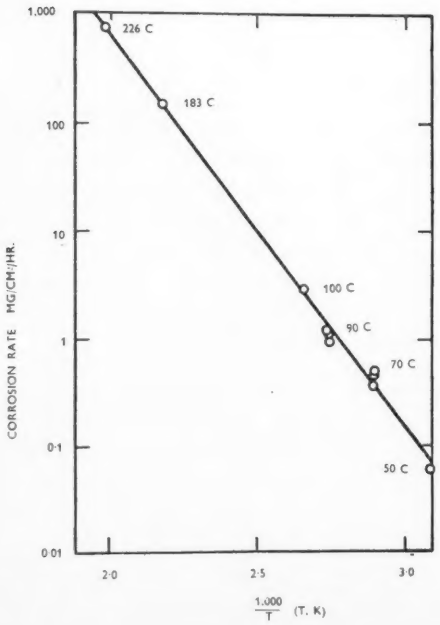


Fig. F.—(Left) Corrosion rate of standard uranium in hydrogen-saturated water (4).

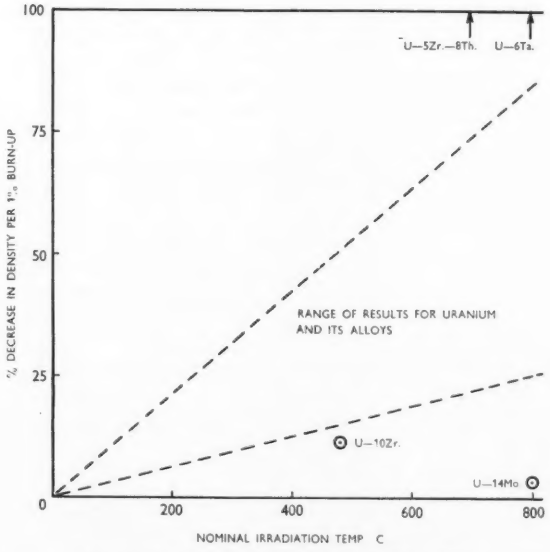


Fig. G.—(Above) Swelling of uranium under irradiation (11).

Data Sheet—cont.

(v) EFFECT OF IRRADIATION ON TENSILE PROPERTIES[19]

For Effects of Irradiation on Hardness See Table 12 in Text

Material	Total Atom burn-up %	Irradiation temp (°C)	Tested at 25°C*			Tested at 300°C*			Tested at 600°C*			Tested at 800°C*		
			U.T.S. (tons/sq in)	0.2 yield stress (tons/sq in)	Elong.% gauge length $4.5\sqrt{A}$	U.T.S.	0.2 Y.S.	Elong. %	U.T.S.	0.2 Y.S.	Elong. %	U.T.S.	0.2 Y.S.	Elong. %
Rolled, beta-treated	0	—	43.4	16.9	19±1	18.3	10.7	32	3.6	2.7	35.0	0.2	0.2	37.0
Uranium	0.018	150	32.3–37.6	24.3–26.9	0.7–0.8	—	—	—	—	—	—	—	—	—
Grain size 0.09–0.12 mm	0.031	150	33.7–41.1	31.0–35.5	0.5–0.8	—	—	—	3.6	2.2	4.5	—	—	—
496 p p m C, 50 p p m Al, 38 p p m Fe	0.075	150	39–39.5	33.5–36.9	0.5	27.5	25.5	0.95	2.6	1.9	1.4	0.4	0.4	7.0–11.0
As above, but canned in NaK	0.062	150	41.6	26.3	0.6	—	—	—	—	—	—	—	—	—
	0.072	300–400	34.8	20.1	0.4									
Beta-treated Uranium	0	—	46.0	13.8	17±1	—	—	—	—	—	—	—	—	—
Grain size 0.09–0.15 mm														
660 p p m C, 48 p p m N_2														
50 p p m Al, 40 p p m Fe	0.072	150	34.0	31.9	0.4	—	—	—	—	—	—	—	—	—
Cast Uranium	0	—	34.8	—	Not known	—	—	—	—	—	—	—	—	—
	10^{19} n v t	Not known	12.3	—	0	—	—	—	—	—	—	—	—	—

*Irradiated specimens were tested out of pile.

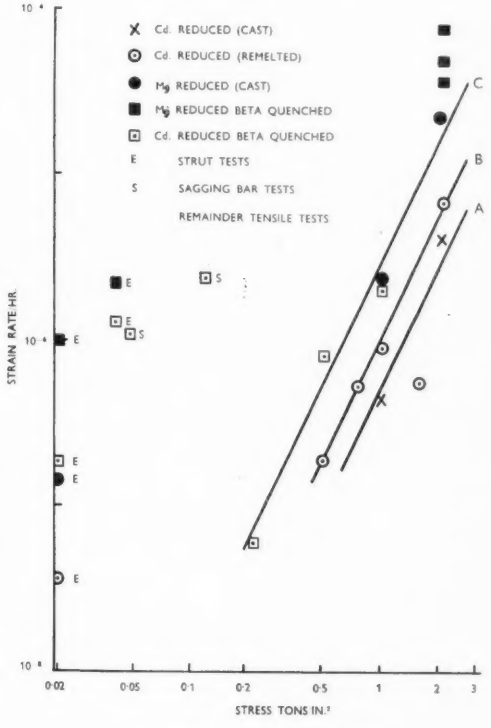


Fig. B.—Creep rates of uranium at 500°C (8).

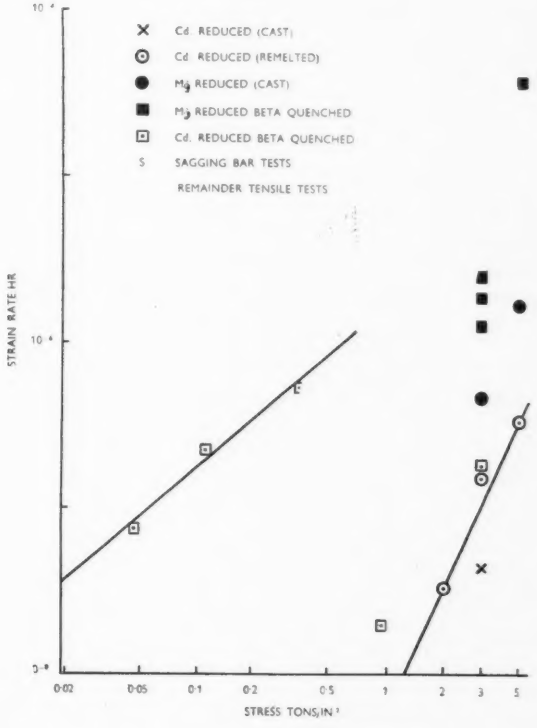


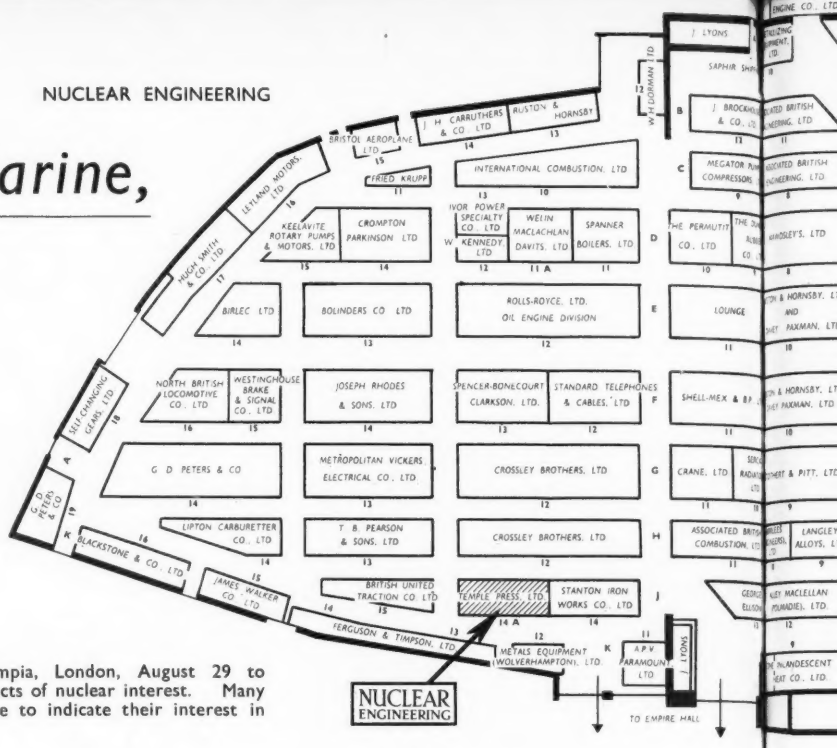
Fig. C.—Creep rates of uranium at 400°C (8).

E. NUCLEAR PROPERTIES[20]

Isotope	% Present in natural U	Half life	Reaction cross-sections at 2200 m/s (Barns)			Neutrons emitted per Fission	Neutrons emitted/neutron absorbed
			Total absorption	Activation	Fission		
Natural U	—	—	7.68	—	4.18	—	1.34
U^{233}	—	1.6×10^5 y	585	52	533	2.54	2.31
U^{234}	0.0057	2.52×10^5 y	92	72	≤0.65	—	—
U^{235}	0.714	7.1×10^8 y	687	107	580	2.46	2.08
U^{238}	99.3	4.5×10^9 y	2.75	2.8	<0.5 mb	—	—
U^{239}	—	23.5 min	—	22	12	—	—

The range of fission products in natural uranium is 6.8 microns (2.7×10^{-4} in).

Engineering, Marine, Welding and **NUCLEAR ENERGY** *Exhibition*



This special Guide to the Exhibition—at Olympia, London, August 29 to September 12—is essentially concerned with products of nuclear interest. Many exhibitors are displaying a Nuclear Energy plaque to indicate their interest in the industry.

Grand Hall, Ground Floor

Of special interest on 11, K, is a guide pan steel casting weighing some 800 lb. This particular guide pan is one of a large number ordered for Hunterston nuclear power station. The manufacturers, **A.P.V.-Paramount** supply corrosion, heat-resisting and alloy steel castings produced by shell, CO_2 and orthodox sand-moulding techniques.

The **Alfa-Laval Co.** (6, F) specialize in equipment for oil, purifying and clarifying; the company is showing gear for the treatment of both turbine lubricating oil and insulating oil in power stations. De Laval plate type heat exchangers offer excellent efficiency when used for oil heating or cooling.

There are many items of interest on 1, D, where **W. H. Allen, Sons and Co.** are displaying pumps, A.C. and D.C. motors, and other electrical equipment including starters. The vertical circulating-water pump shown is of the double-suction, centrifugal type for condenser circulating-water duty and is typical of many similar pumps installed or on order for new power stations. It is designed for an output of 990,000 gallons of water per hour against a total head of 29 ft, when running at a speed of 485 r.p.m.

Hydraulic methods of remote control are displayed on 4, D by **Automotive Products.** Exhibits include pump accelerator units, motors, control, relief and semi-rotary slave valves. There is also a typical Lockheed centralized control cabinet for a power station.

For material testing **W. and T. Avery** are exhibiting a new range of machines represented on 3, H by Universal units of 50 tons and 12,000 lb capacities.

Babcock and Wilcox are devoting a good deal of space to nuclear developments on 4, G. Apart from a number of wall charts and diagrams, exhibits include a sectional model of one of the thirty-two heat exchangers being supplied to Calder Hall and Chapelcross and a scale model of a typical welded pressure vessel for a pressurized water reactor. Associated with this model there are samples of a "push-out" formed in 6-in. steel plate and a weld between very thick plates—indicative of manufacturing techniques required in the construction of reactor pressure vessels. Samples of nuclear fuel cans and of the finned tubing used in a heat exchanger; a model of a Dido loop and a model indicating the possible arrangement of a nuclear propulsion plant based on a gas-cooled reactor in the hull of a large tanker are also on show.

New developments in packings are being featured by **Beldam Asbestos Co.** on 3, D. The company makes jointings and packings for steam and chemical lines.

A four-way welding fume exhaust unit can be seen on 1, A. The makers, **Keith Blackman,** have developed this versatile portable equipment for the extraction of fumes from the interior of fabricated vessels during welding. Up to four welding positions as far as 60 ft apart can be handled this way.

A special nuclear energy display is featured on the stand of the **British Engineers Association.** The B.E.A. provides the secretariat for the Nuclear Energy Trade Associations' Conference, of which it is a founder member.

British Ropes feature a representative selection of their products on 2, K.

Velan steam traps for pressures of up to 2,500 p.s.i. and temperatures of up to 1,100° F. can be seen on 10, J. The manufacturers, **British Steam Specialities,** are also introducing the new Vee-Reg/Rotork electrically operated valve for remote control applications.

For plate levelling, **Bronx Engineering** exhibit, on 6, A, a seven-roll plate levelling machine which will handle plates up to ½ in. thick by 6 ft wide. The Bronx 8-ton hand-operated press can be used for one-off or production runs with equal success.

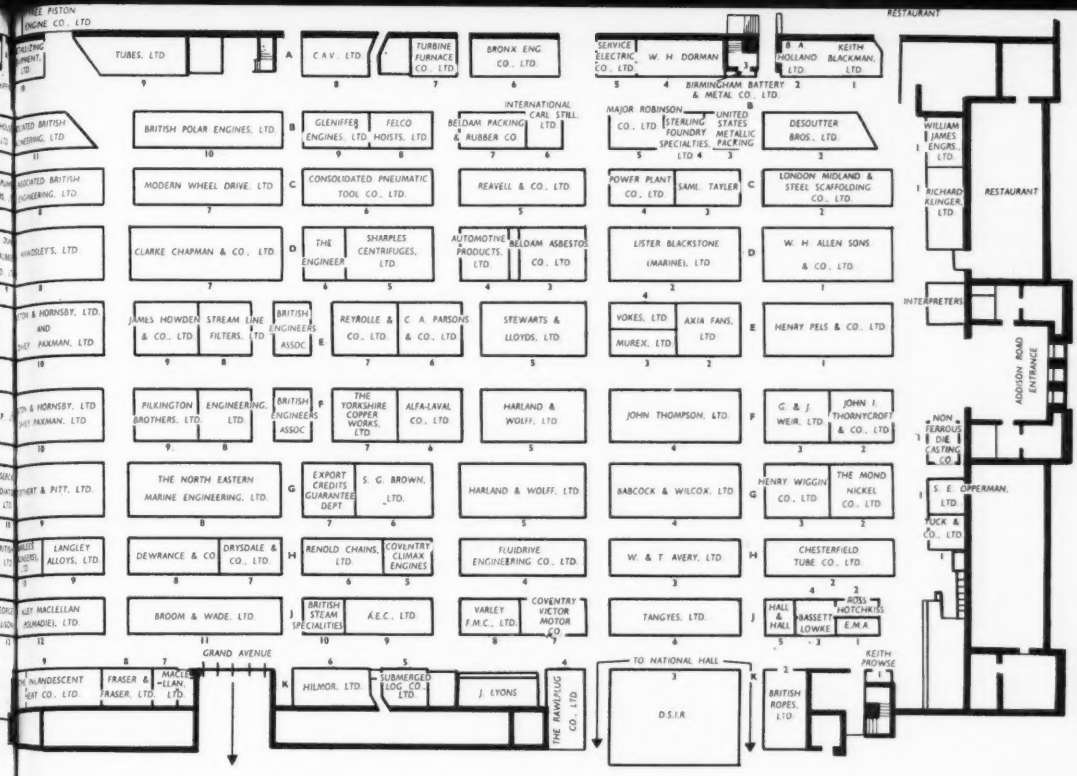
A new product on 11, J is the **Broomwade** C660 dry-cylinder, carbon-ring single-stage compressor which has an output of 100 c.f.m. F.A.D. at 100 p.s.i. In the pneumatic tool range there is a new drill, the MV.60 with an exceptionally high torque.

A complete range of miniature and fractional h.p. motors and servo-motors is featured by **S. G. Brown** on 6, G.

Electric overhead cranes made by **J. H. Carruthers** include a model specially developed for the Dounreay fast breeder reactor. A selection of the company's other products, including large reciprocal and centrifugal pumps, appears on 14, A.

Seamless stainless steel tubes and vessels made from fully austenitic weld decay-free molybdenum and tungsten bearing steels are being exhibited by **Chesterfield Tube** on 2, H.

A new underwater lighting fitting can be seen on the stand of **Clarke, Chapman** (7, D). The fitting is manufactured by E. N. Mackley and Co. to a patent of U.K.A.E.A. Of aluminium construction, the lampholder body has a sealed side cable gland entry which gives access to the connection of the lampholders. When the special lamp is screwed in position correct alignment is certain. The structure and the water sealing arrangements will withstand pressure at depths of up to 1,500 ft.



From their comprehensive range of over 480 different power tools **Consolidated Pneumatic Tool** show several new models on 6, C. The new Hicycle grinder operates with tungsten carbide burrs at 25,000 r.p.m.

On the stands of **Crossley Bros.** (12, G and H) Crossley Premier Engines are showing a 240 b.h.p. two-cycle Diesel generating set with flange mounted generator as used to provide auxiliary power. Crossley supplied generating sets for use at Calder Hall.

Dewrance valves for the control of CO_2 and similar fluids in nuclear power stations are to be seen on 8, H. The bodies of the valves are in carbon or alloy steel stampings, with seats directly deposited with Endewrance, a hard-faced non-corrodible alloy, capable of withstanding severe service conditions. The valvehead is of stainless steel and is amply guided so that the valve forms a true seating. A special feature of this design are the bellows above the valvehead to prevent leakage of fluid between the spindle and the gland. The cover is also tip welded to ensure that there is no leakage at the cover joint. This design is available in sizes up to 10 in., the larger sizes having bodies fabricated from steel tubing.

For transformer oil circulation, **Drysdale** show on 7, H, the Capsule, a horizontal axial flow pump with the motor totally enclosed in the casing.

Dunlop Rubber feature examples of a new synthetic called Duthane on 9, D. Expansion joints for steam services and heat resisting conveyor belting are also displayed.

Medium voltage control gear mounted in flush-fronted cubicles can be seen on 1, J. **Electro-Mechanical Manufacturing** are supplying Y-unit indoor/outdoor industrial switches and switch fusegear to Berkeley power station.

Adjust-a-leg equalizing sling is a complete lifting assembly for loads of unusual size, shape or unbalanced weight—is shown by **Felco Hoists** on 8, B.

Rotating parts of a 22.25 DST (double-circuit scoop trimming) fluid coupling rated at 3,000 h.p. at 3,000 r.p.m. form the centre of interest on 4, H. **Fluidrive Engineering** are producing a large number of these couplings for gas circulator drives and high power boiler feed pumps at nuclear power stations. There are also two working models of SSS (synchro-self-shifting) clutches.

Electric generators for both AC and DC systems, together with AC and DC motors, are displayed by **Harland and Wolff** on 5, F and G.

A general purpose non-mandrel bender is being demonstrated for the first time on 6, K. This heavy-duty machine by **Hilmor** can handle up to 5 in. dia non-ferrous and 4½ in. dia ferrous with bends of up to 180°.

Rotary compressors and vacuum pumps for capacities ranging from 3 c.f.m. to 8,400 c.f.m., pressures from 2 p.s.i. to 250 p.s.i., and vacuum up to 99.5% are made by **B. A. Holland Engineering;** representative examples are shown on 2, A.

James Howden specialize in the manufacture of equipment for moving, compressing or cleaning air or gas and for transferring heat from one fluid to another. Their exhibit, on 9, E, includes a 200 mm compressor with casing sectioned to display the rotors.

Laboratory equipment is included in the display by **International Combustion** on 10, C. The company also make a wide range of engineering equipment. It is a joint owner of Atomic Power Constructions.

A 1-ton winch driven by a gear-type hydraulic motor is exhibited on 15, D, by **Keelavite Rotary Pumps and Motors.** A variable speed drive gives a maximum speed of 80 ft per minute.

Compressed asbestos jointing; moulding in a wide range of materials, gauges, valves and cocks can be seen on 1, C. **Richard Klinger** supplied a large quantity of sleeve-packed cocks for use in connection with burst slug detection at Calder Hall.

Corrosion resistant valves by **Langley Alloys** (9, H) include globe, gate and Y-type in nickel base alloys, stainless steels and Hidurax aluminium bronze.

Scols tube benders made by **Major Robinson** and shown on 5, B, can be arranged for hand, hydraulic or electric power operation. Capacities range from ¼ in. to 6 in. dia., bent cold without loading. The latest Scols lever bending machine handles rods and flats.

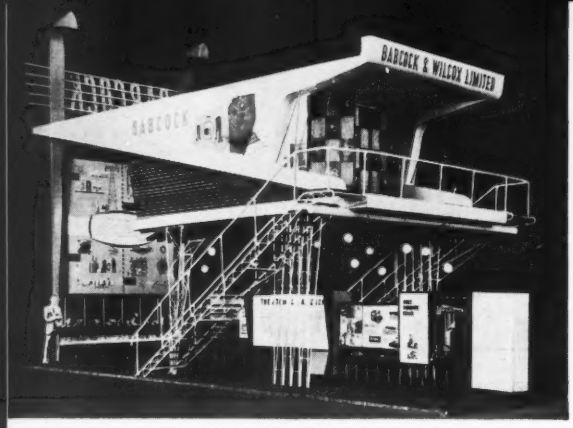
New liquid relief valves can be seen on 9, C. These valves, made by **Megator Pumps and Compressors,** are of bronze with cadmium-plated carbon-steel valve springs.

One of the new developments announced by **Metallizing Equipment** is the Thermo Spray process shown on 10, A. The gun will deposit quickly high-melting-point ceramics or hard-facing alloys without using compressed air. As a heat barrier, for example, zirconia has a melting point of 4,600°F.

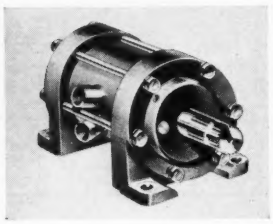
Mond Nickel on 2, G, aim to help engineers to pick the right material for the job. Spheroidal graphite cast iron, platinum metals and nickel alloys are all featured.

Murex (3, E) are displaying zirconium rod, sheet, wire, tube and fabricated parts for both nuclear application and corrosion-resistant plant.

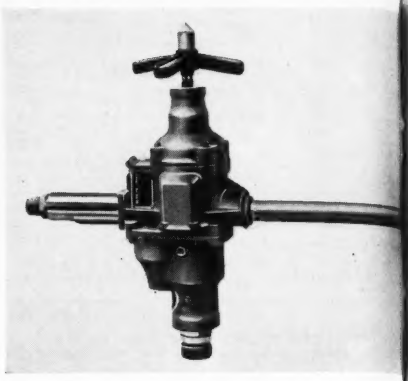
Nuclear Engineering's own stand is 14_A, J. Readers who require back numbers or general information about the journal are invited to the stand, where a representative selection of other journals published by **Temple Press** can also be seen.



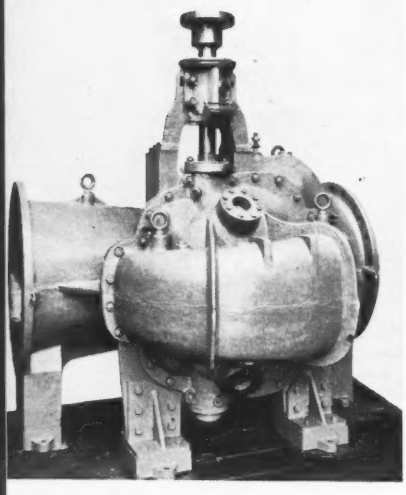
(Above) Impression of the Babcock and Wilcox stand.



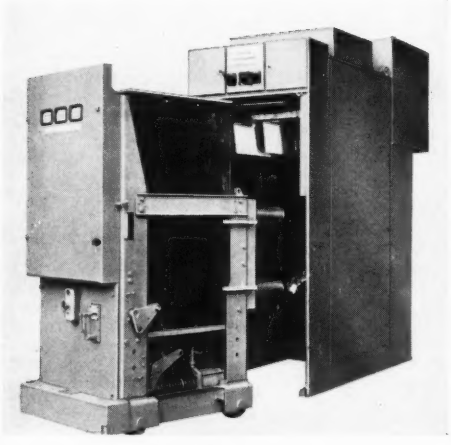
(Above) Lockheed semi-rotary slave unit by Automotive Products.



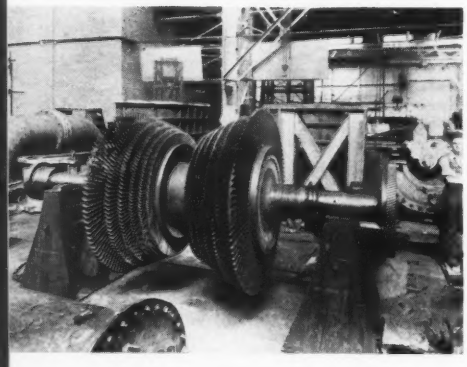
(Right) Broomwade MV 60 high-torque pneumatic drill.



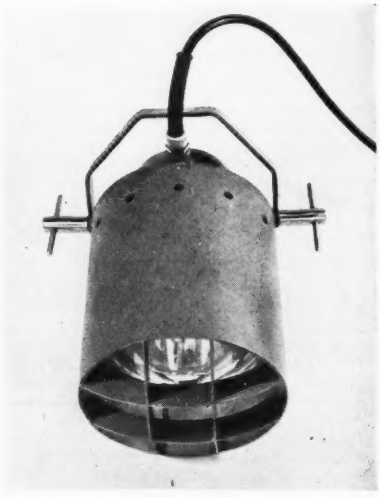
Allen vertical, double-suction, centrifugal circulating water pump.



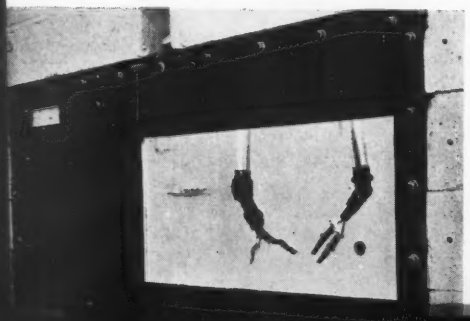
Reyrolle 11-kV 500-MVA air-break circuit-breaker.



Low-pressure turbine shaft for 23 MW Parsons alternator.



(Above) Underwater lighting fitting to A.E.A. specification (Clarke, Chapman).



(Left) Protective glass window made by Pilkington Bros.

Grand, ground, (*contd.*)

Opperman Gears products on 20, Q, include horizontal foot-mounted geared motors from fractional to 60 h.p.; vertical flange-mounted geared motors of up to 25 h.p., with single reduction geared motors of helical and worm types, together with a selection of speed reducers.

Not surprisingly, the central exhibit on 6, E, is a completely bladed low-pressure turbine shaft for one of the sixteen 23 MW turbo-generators which **C. A. Parsons** are supplying to Calder Hall A and B and Chapelcross nuclear power stations. Large coloured photographs show the interior of Calder A station and the external appearance of Bradwell nuclear power station. As a member of The Nuclear Power Plant Co. Ltd., Parsons are supplying the Bradwell power plant comprising six 52 MW turbo-generators and three 20.25 MW auxiliary turbo-generators together with condensing plant, dump condensers, gas circulators and gas duct work.

A new combined high-speed shears and nibbler for ¼-in. plate and a press brake with a capacity of $\frac{5}{16}$ in. is exhibited on 1, E, by **Henry Pels.**

Deminrolit plant for treating boiler feed and process water and the application of ion exchange for removing uranium from leach liquids is featured by **Permutit** on 10, D.

Demonstrations of welding with Lion electrodes are being given by **G. D. Peters** on 19, A.

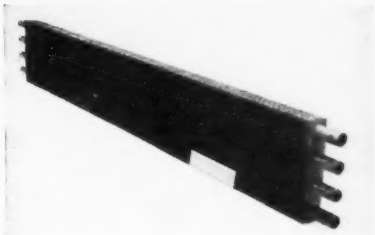
Theme of 9, F, is "Glass as a protective material" and, as one might expect, **Pilkington Bros.** pay special attention to stabilized and dense glasses for protection against hard X-ray and gamma emission; glass for protection from pressure or blast and glass linings which resist corrosive and mechanical attack.

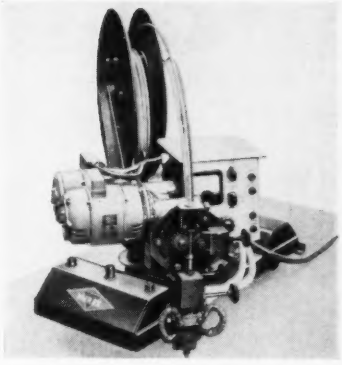
Thousands of **Rawlplug** fixing devices have already been used in nuclear power station construction and the company is showing (4, K) a model of Calder Hall together with a record of the various ways in which Rawlplugs can be used. With the aid of a Rawlplug durium-tipped drill holes from 5/32 in. to 1 in. dia. can be bored in masonry of up to 16 in. thickness.

(Left) Hilmor non-mandrel bender, H.M-4B.

(Right) Murex Muramatic automatic welding equipment.

(Below) Bank of finned tubes (Tubes, Ltd.).





The selection of air compressors on 5, C, includes a two-stage, double-acting vertical compressor of 1,500 c.f.m. capacity for pressures of up to 120 p.s.i. together with many other single- and multi-stage units developed by **Reavell.** The company supplied compressors for use at Calder Hall.

Renold transmission chains from .25 in. pitch to 4 in. pitch together with associated drive wheels can be seen on 6, H. **Renold Chains** are also featuring two working models —one demonstrates applications other than power transmission.

Reyrolle are showing on 7, E, a new 11-kV 500-MVA horizontal-drawout air-break circuit-breaker in which cast resin is extensively used for insulation. Normal current ratings up to 2,000 A are available and the busbars have a rating of 2,400 A. Reyrolle also feature a selection of their variable-speed a.c. commutator motors. Outputs range from 5 to 60 h.p. and the units incorporate direct-handwheel, remote-mechanical, and remote-electrical methods of speed control.

Representative examples from the wide range of **Richardsons Westgarth** products can be seen on 8, G.

Although the display of **Ruston and Hornsby** and **Davey Paxman** (10, E and F) is mainly concerned with Diesel and gas-turbine power units, the latter company has recently made a prototype fabricated valve body of 54-in. diameter for Calder Hall.

Centrifugal fans for maintaining a pressure differential in glove boxes or cooling electronic equipment are shown by **Service Electric** on 5, A.

On 10, G, **Serck Radiators** feature a composite display unit showing tube stacks in stainless steel and bi-metals accompanied by stacks with internal secondary surfaces and both internal and external secondary surfaces.

Clothing providing protection for personnel handling radioactive materials, including respiratory apparatus and a new pressure suit, can be seen on the stand of **Siebe Gorman** (3, T).

Where powdered material has to be divided up according to particle size, **Sharples Centrifuges** offer a Super Classifier operating on the air vortex principle. The machine is exhibited for the first time on 5, D.

The development of lubricants to meet new conditions is the theme of the **Shell-Mex and B.P.** exhibit (11, F). Work on radiation resistant oils for nuclear power stations is also described.

A model of a 3,000-ton vertical bending press can be seen on the stand of **Hugh Smith** (17, A). This machine is capable of cold bending $2\frac{1}{4}$ in. plate, 10 ft. long to a minimum circle diameter of 6 ft. The thickness of material is considerably increased when the shells are hot. The company also manufacture 4-column presses with powers of up to 2,000 tons. These machines are capable of forming hemispherical ends and spherical segments.

The latest Stanelco equipment for soldering, brazing, annealing and hardening can be seen on 12, F. **Standard Telephones and Cables** are also showing a number of newly designed induction generators.

Safway equipment being shown by **Sterling Foundry Specialities** on 4, B—is claimed to be the first welded unit frame scaffold.

Manipulated pipework for both high and low pressures and temperatures and boiler tubes, both seamless and electric resistance welded is featured by **Stewarts and Lloyds** on 7, E. Amongst other items of interest there is a range of Dawson joints and Viking Johnson couplings.

Transformer oil filters by **Stream-Line Filters** are being supplied to Chapelcross, Dounreay and Berkeley. Similar units—which make use of the well-known Stream-Line edge filtration process—are shown on 8, E.

New Hydralite jacks shown by **Tangyes** on 6, J, include a model of 35-ton capacity with an 18 in. power lift and a 100 ton version with a 6 in. lift. The latter incorporates a two-speed hand pump of new design.

Exhibits on 4, F relate to **John Thompson's** work for the fast-breeder reactor at Dounreay and, in conjunction with the A.E.I. John Thompson Nuclear Energy Co. Ltd., for Berkeley nuclear power station. A sectionalized model of No. 1 reactor and associated heat exchangers at Berkeley includes an illuminated circuit indicating the course taken by the coolant CO_2.

Extended surface tubes for heat exchangers can be seen on 9, A, where **Tubes** have a selection of their products. Extended surface tubes can be supplied in banks of from one to four tubes according to the particular requirement. In addition to a range of precision seamless steel tubes, the company also exhibits some interesting tubular forgings.

Packings for practically every stuffing box requirement are displayed by **United States Metallic Packing** on 3, B. The company also make steam traps, cocks and valves and pneumatic and hydraulic equipment.

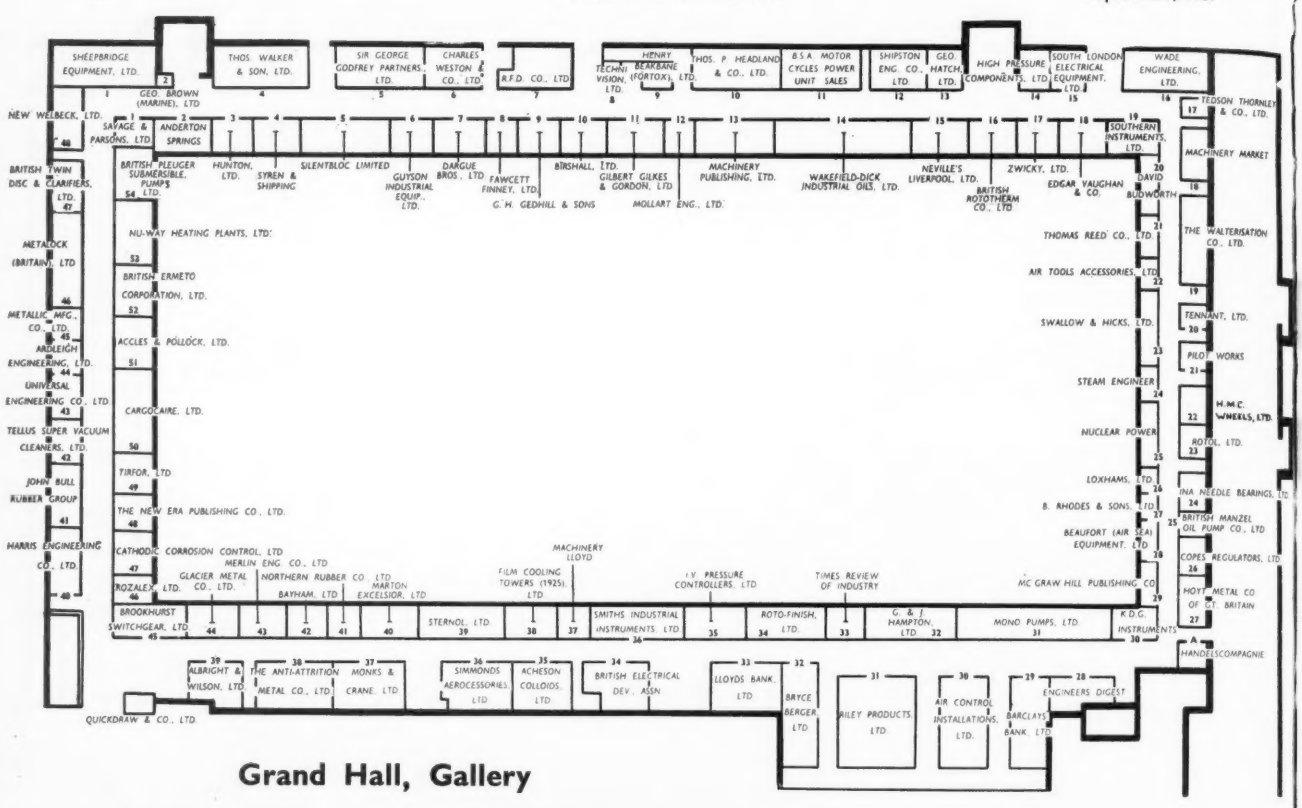
A complete range of pumping equipment on 8, J **(Varley-FMC),** includes motorized coolant pumps for machine tools, gear pumps for forced lubrication and packaged hydraulic tank units.

Among the many new products introduced by **Vokes** on 4, E, the foremost is the Auto-Roll—an automatic screen air filter with the medium placed between two rollers so that a clean filter cloth is obtainable by turning the lower roller. A new departure in lubricating oil filter elements and a warning indicator for dirty elements and radioactive dust particle filters are also on display. Vokes Genspring feature their variable and constant support hangers, models H12 and W for applications where a thermal expansion problem arises in pipe lines.

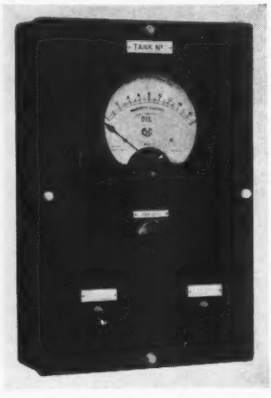
Principal nuclear interest on the stand of **G. and J. Weir** (3, F) is a model of the Weir/English Electric canned pump developed for nuclear power plants. Boiler feed pumps and air compressors are also displayed.

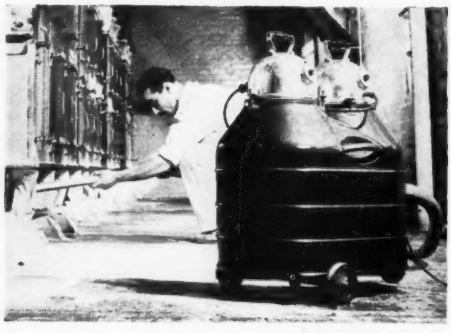
Among the compressors shown by **Williams and James** on 1, B, is a unit for boosting air from 800 p.s.i. to 6,000 p.s.i. The W. & J. Pneumerstat for gas purging or liquid level measurement is shown in operation.

Yorcalbro and Yorcoron condenser tubes for power stations are featured by **Yorkshire Copper Works** on 7, F.



Grand Hall, Gallery



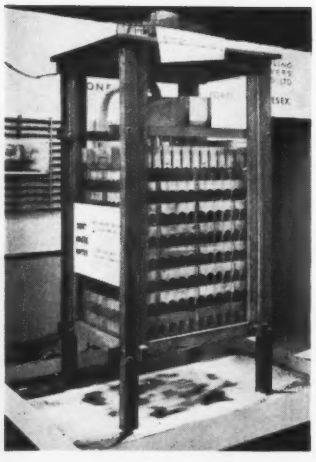


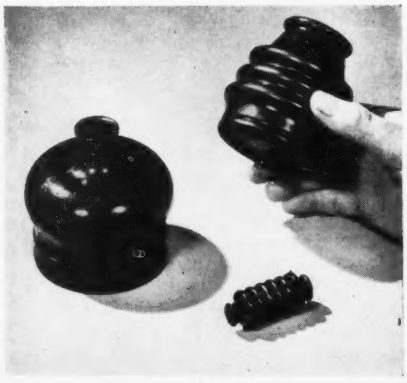
(Above) New Welbeck Duplex vacuum cleaner.

(Left) Bayham panel with remote reading contents gauge.

(Left, below) All-film-flow cooling by Film Cooling Towers.

(Below) Gaiters and bellows in Prescollan. (John Bull).





An extremely large variety of tubes can be seen on 51, Inner. **Accles and Pollock,** feature examples of seamless stainless steel tubing, precision tubes, special sections, tubes in metals such as zirconium, tantalum, titanium, molybdenum, vanadium and niobium, together with thin-walled, flexible and extended surface tubes.

The main feature on 35, Outer, is a display of various industrial products during the manufacture or treatment of which "dag" dispersions of colloidal graphite and colloidal molybdenum disulphide play an important part. **Acheson Colloids** are also showing equipment pre-treated to provide "built-in" dry lubrication; packings and bearings in which "dag" colloidal graphite is impregnated or incorporated, and a range of "dag" products including glass dispersions and the new rubber lubricant "Gredag" graphited grease grade R.B.5.

Filters for ventilation equipment which are self-maintaining can be seen on **Air Control Installation's** stand, 30, Outer.

Metal finishing is the theme of 39, Outer. **Albright and Wilson** are featuring Kanigen —a nickel phosphorus alloy deposited by chemical reduction. Chemical polishing for aluminium alloys will also be demonstrated.

Anderton Springs display on 2, Inner, circlips ranging from those for $\frac{1}{16}$-in. to 15-in. dia. shafts and $\frac{1}{4}$-in. to 15-in. bores.

Bayham (42, Inner) are displaying their range of R. and G. direct and remote reading contents gauges, flow indicators and relays for flow rates between $\frac{1}{2}$ g.p.m. and 840 g.p.m. R. and G. level controls and switches give automatic pump control and warning of high or low liquid levels.

Fortox leather bellows and covers (9, Outer) made by **Henry Beakbane** are extensively used to protect slideways, lead screws and rams on precision machinery. Smallest internal diameter is 1 in. and the largest 48 in.: the expanded length of the bellows can be up to 35 ft.

Electrical methods of heat treatment and ultrasonic thickness gauging are but two of the subjects dealt with on **British Electrical Development Association's** stand, 34, Outer.

The **British Ermeto** pipe coupling on 52, Inner, will withstand very high pressures—even under conditions of extreme vibration. It is extensively used in hydraulic control systems.

British Pleuger submersible pumps for power station applications are shown at 54, Inner.

Dial thermometers, recorders and controllers on 16, Inner, are manufactured by **British Rototherm.** The series of distant reading and rigid stem vapour pressure thermometers includes versions with dials of from 2½ in. to 8 in.

The large amount of **Brookhurst** switchgear provided for nuclear applications is emphasized on 45, Inner, by a photographic display of gear provided for Calder Hall, Dounreay and Chapelcross. The new Chester Minor switchboard is both flexible and accessible because of unit construction.

The **John Bull** group of companies, which include John Bull Rubber, Metalastik and Precision Rubbers, are displaying a wide range of products in natural and synthetic rubbers and of rubber-to-metal bonded construction on 41, Outer. Precision Rubbers are featuring Prescollan, a new rubber-like material with exceptional tear and abrasion resistance.

Amongst the range of flow regulators on 26, Outer **(Copes Regulators)** there is a GA regulating valve for feed water representative of an order which the company has in hand for Bradwell nuclear power station. A feature of this valve is the adjustable flow area and the use of a tension-type thermostat.

For the drawing office **Dargue Bros.** feature (7, Inner) their latest space-saving modular furniture.

Main exhibit on 38, Inner, is a full-scale working model of an induced draught cooling tower. Made by **Film Cooling Towers** the tower has a transparent cladding showing the internal working of the all-film-flow packing. Sixteen of these packaged coolers are being supplied to Calder Hall and Chapelcross.

A range of pressure relief valves, vacuum pumps, industrial blowers and a diaphragm pump can be seen on the stand of **Sir George Godfrey and Partners** (5, Outer).

Air-operated shotblast cabinets with unique design principle giving economical running costs shown by **Guyson Industrial Equipment**, 6, Inner.

High Pressure Components (14, Outer) specialize in pipe fittings and couplings. GYP screw-down valves in mild steel, stainless steel and bronze are suitable for handling fluids and gases over a wide temperature and pressure range.

Designers and manufacturers of pressure control equipment, **I.V. Pressure Controllers** are showing on 35, Inner, complete control panel and testing units for both hydraulic and pneumatic applications. The company make hot gas valves specifically for nuclear applications.

Mercury-in-steel thermometers have been supplied by **K.D.G. Instruments** (30, Inner) to Calder Hall, Dounreay and Harwell. The company is also featuring other products which have been supplied to U.K.A.E.A.—including pressure and differential pressure switches used as safety devices together with differential pressure, contacting pressure and liquid level gauges.

A number of specialized products for nuclear energy applications figure prominently among **Marston Excelsior** exhibits on 40, Inner. These include a fuel element as used in Dido, a heat exchanger and stainless steel tubes furnace-brazed into a mild steel header plate. These tubes are representative of those supplied to Calder Hall for burst slug detection.

Gaskets, shims and liners for use in nuclear engineering are featured by **Metallic Manufacturing** on 45, Outer.

The **Metalok** process on 46, Outer, offers a method of effecting cold repairs to a cracked or fractured casting. Steam leaks can be sealed under pressure by Furmanite.

Universal joints by **Mollart Engineering** (12, Inner) are extensively used in radioactive handling manipulators.

D-type cast iron pumps and H-type stainless steel pumps used for handling activated sludge and slurries for uranium extraction are to be found on 31, Inner. Both models are made by **Mono Pumps.**

New Welbeck industrial suction cleaners on 48, Outer, operate on a unique principle: dirt and dust is collected in a metal canister. The company make one model, the Bak-Vak which can be strapped to the back for transportation to difficult positions.

Protective clothing featured by **R.F.D.** (7, Outer) includes the Harwell updraft helmet, flame-proof, quick release overalls for protection against sodium hazards and a new self-contained compressed air fire fighting set.

Sight flow indicators are given prominence on the stand of **B. Rhodes** (27, Inner). Sizes range from ¼-in. bore to 8-in. bore—probably one of the widest ranges ever shown in this type of fitting.

Barrier creams have found many applications in nuclear engineering and **Rozalex** are showing on 46, Inner, a new cream specially formulated for the rapid decontamination of protective clothing worn by personnel exposed to radioactive materials.

Remote handling equipment for radioactive and toxic materials appears on **Savage and Parsons** stand, 1, Inner. Developed in conjunction with A.E.R.E., Harwell, exhibits include a master slave manipulator, handling devices, lead shielding bricks and pots.

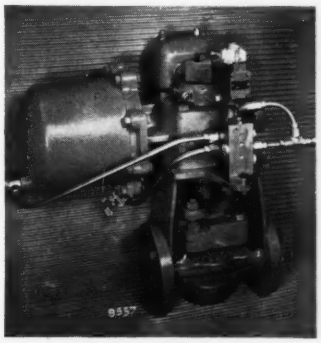
Anti-vibration mountings by **Silentbloc** appear on 5, Inner. A subsidiary, Andre Rubber, specializes in bonding rubber to metal and makes Neoprene/nylon flexible expansion pieces in sizes from 2-in. dia to 60-in. dia.

The Hydrostatic gauge featured by **Simmonds Aerocessories** (36, Outer) operates by compressed air or by hand pump to provide remote reading of tank contents. The company are also displaying other types of level and flow gauges.

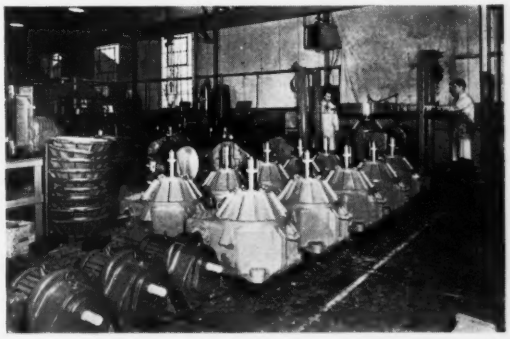
For recording transient variables **Southern Instruments** Oscillograph Division offer a wide range of oscilloscopes, some of which are featured on 19, Inner. Most recent development is the completely self-contained M 977 double-beam oscilloscope.

Although specific attention is not being paid to nuclear-grade lubricants on 14, Inner, **Wakefield-Dick** were recently nominated as suppliers of lubricants to Berkeley. The company supplied transformer oil for Calder Hall and expects to provide turbine oils at Chapelcross.

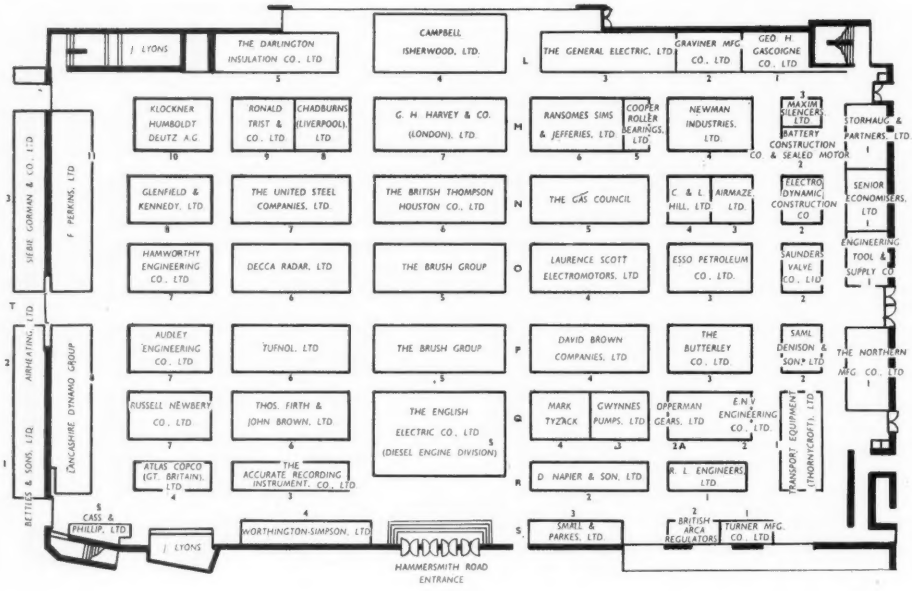
Metal treatment is the concern of 19, Outer, where the **Walterisation Co.** feature methods of rust-proofing and paint bonding. In addition, the DX processes facilitate cold forming and extrusion of steel blanks.



2-in. C.I. Audco valve with No. 3 cylinder operator (Audley Engineering).



Cooling tower fan drive gears (Opperman Gears).


J. LYONS
THE DARLINGTON INSULATION CO., LTD.
CAMPBELL ISHERWOOD, LTD.
THE GENERAL ELECTRIC, LTD.
GRAVINER MFG. CO., LTD.
GEO. H. GASCOIGNE CO., LTD.
KLOCKNER HUMBOLDT DEUTZ A.G.
RONALD TRIST & CO., LTD.
CHADBURNS (LIVERPOOL) LTD.
G. H. HARVEY & CO. (LONDON), LTD.
RANSOMES SIMS & JEFFERIES, LTD.
COOPER ROLLER BEARINGS, LTD.
NEWMAN INDUSTRIES, LTD.
MAXIM SILENCER CO., LTD.
BATTERY CONSTRUCTION & SEALED MOTOR CO.
STORHAUG & PARTNERS, LTD.
SIEBE GORMAN & CO., LTD.
F. PERKINS, LTD.
GLENFIELD & KENNEDY, LTD.
THE UNITED STEEL COMPANIES, LTD.
THE BRITISH THOMPSON HOUSTON CO., LTD.
THE GAS COUNCIL
C. & L. HILL, LTD.
AIRMAZE, LTD.
ELECTRO DYNAMIC CONSTRUCTION CO.
SENIOR ECONOMISERS, LTD.
HAMWORTHY ENGINEERING CO., LTD.
DECCA RADAR, LTD.
THE BRUSH GROUP
LAURENCE SCOTT ELECTROMOTORS, LTD.
ESSO PETROLEUM CO., LTD.
SAUNDERS VALVE CO., LTD.
ENGINEERING TOOL & SUPPLY CO.
AIRHEATING, LTD.
LANCASHIRE DYNAMO GROUP
AUDLEY ENGINEERING CO., LTD.
TUFNOL, LTD.
THE BRUSH GROUP
DAVID BROWN COMPANIES, LTD.
THE BUTTERLEY CO., LTD.
SAML DENISON & SON, LTD.
THE NORTHERN MFG. CO., LTD.
BETTES & SONS, LTD.
RUSSELL NEWBERY CO., LTD.
THOS. FIRTH & JOHN BROWN, LTD.
THE ENGLISH ELECTRIC CO., LTD. (DIESEL ENGINE DIVISION)
MARK TYZACK
GWYNNES PUMPS, LTD.
OPPERMAN GEARS, LTD.
E.N.V. ENGINEERING CO., LTD.
TRANSPORT EQUIPMENT (THORNYCROFT), LTD.
ATLAS COPCO (GT. BRITAIN), LTD.
THE ACCURATE RECORDING INSTRUMENT CO., LTD.
D. NAPIER & SON, LTD.
R. L. ENGINEERS, LTD.
CASS & PHILLIP, LTD.
J. LYONS
WORTHINGTON-SIMPSON, LTD.
SMALL & PARKES, LTD.
BRITISH ARCA REGULATORS
TURNER MFG. CO., LTD.
HAMMERSMITH ROAD ENTRANCE

National Hall, Ground Floor

Accurate Recording Instrument Co. have based their display (3, R) on instruments which the company has supplied for use at Calder Hall. These include seal oil/gas differential pressure gauges, 3-15 p.s.i. repeater units and special transmitting pressure gauges.

Audley Engineering (7, P) specialize in the manufacture of lubricated taper plug valves. Made in a wide range of materials in sizes of up to 24 in. they are designed for controlling pressures from the finest vacuum up to 5,000 p.s.i. One of the features of the stand is the application of power operated remote controlled valves.

In addition to representative examples of the company's wide range of products **BTH** is showing on 6, N, a drawing of Berkeley power station. BTH is, of course, a joint owner of the A.E.I.-John Thompson Nuclear Energy Co. Ltd.

The new **David Brown** Varicon stepless speed reducer (4, P) for drives of up to 5 b.h.p., is a hydraulically-operated gear unit which provides steplessly variable output speeds ranging from the original input speed to zero and back again, whilst transmitting full rated load. Other David Brown exhibits include castings and gears of many different types.

Butterley feature on 3, P, a small, self-contained oxygen generating plant complete with all accessories.

Split roller bearings shown by **Cooper Roller Bearings** on 5, M, have a particular advantage where ease of assembly and continuous service are paramount. The split feature enables bearings to be assembled on the shaft without disturbing adjacent equipment. Sizes range from 1¼ in. to 30 in. bore.

Four companies of the **Darlington** group are represented on 5, L. The Chemical and Insulating Co. are makers of insulating and finishing material, such as 85% magnesia for temperatures of up to 650°F, metadextramite for up to 1,200°F and dextramite for up to 2,000°F. These materials, in pre-formed sections, slabs or moulds or powder form, are installed by The Darlington Insulation Co. The British Refrasil Co. processes insulating material for temperatures of up to 1,000°C. Finally, S. T. Taylor and Sons show examples of their sheet-metal and platework.

As specialists in gears and transmission assemblies, **E.N.V. Engineering** (2, Q) are featuring examples from their spiral bevel, zerol and hypoid gears, ranging from 1-in. diameter up to 52-in. diameter. The company expects to show a pair of dry-lubricated bevel gears developed in conjunction with BTH for actuating the control rods at Berkeley nuclear power station.

Among several large exhibits on the stand of **Thos. Firth and John Brown** (6, H) there is a monobloc rotor, length 18 ft 8 in., diameter 4 ft 6 in., weighing 31½ tons.

A model of the G.E.C. Simon-Carves nuclear power station which is being erected at Hunterston for the South of Scotland Electricity Board is one of the principal exhibits on the **G.E.C.** stand (3, L). Hunterston will have a generating capacity of 360 MW of which 300 MW rising to 320 MW will be fed to the national grid.

Body and door of a prototype gate valve for coolant gas in a reactor are featured by **Glenfield and Kennedy** on 8, N.

Graviner Manufacturing display on 2, L, examples from the range of specialized nuclear equipment developed by the company.

An interesting exhibit on 3, Q, is a working experimental model of suction inlets to cooling water main circulating pumps. **(Gwynnes Pumps.)**

G. H. Harvey and Co. (London) (7, M) have a wealth of experience in welded fabrication and their heavy construction and fusion welding shops are developing automatic techniques for welding high tensile steels. An associate company, Nuclear Engineering specialize in industrial applications of radioactive isotopes—particularly for radiographic purposes.

Specializing in the casting of non-ferrous metals, **C. and L. Hill** (4, N) offer industrial radiological facilities.

Hydraulic pumps, systems and jacks, air compressors and selector valves can be seen on 1, S. **Hydraulic and Pneumatics** is a subsidiary of Turner Manufacturing Co.

A representative selection of products from sixteen companies in the **Lancashire Dynamo** group can be seen on 8, P. Included are a.c. and d.c. motors and generators; transformers of up to 3,000 kVA, rectifiers, variable speed drives, industrial electronic equipment and switchgear.

Trislot high torque squirrel cage motors driving typical auxiliaries can be seen on 4, O. **Laurence Scott and Electromotors** claim that this motor has a higher starting performance (i.e. starting torque/starting current ratio) than is obtainable with a normal squirrel cage motor.

Saunders Valve (2, O) are exhibiting their diaphragm valve. Sizes range from ¼ in. for laboratory work to large stainless steel units as used for the control of heavy water in Dido-type reactors. Many valves are actually demonstrated—including a diaphragm operated pressure-opening valve with an automatic device which closes the line in the event of pressure failure.

Neoprene and fabric seals for steam plant and packings and jointings are exhibited by **Small and Parkes** on 3, S.

Tufnol sheet that is highly resistant to chipping or cracking and is thus eminently suitable for panelling switchboards, is featured on 6, P. Other forms of this versatile material include tubes and rods.

The **United Steel** companies are occupying a two-tier stand (7, N). Appleby-Frodingham Steel Co. feature steel plates: Steel Peech and Tozer are responsible for a number of forgings, and Samuel Fox and Co. feature stainless steel springs for water pumps.

From their new OCR two-stage rotary oil-cooled air compressors **Worthington-Simpson** show two machines on 4. S. The company also make chemical pumps in Worthite and 18/8/3 stainless steel for handling acids, alkalis and slurries.

Heavy-duty cylinders for pneumatic and hydraulic application are featured by **Martonair** on 23, Outer. There is a choice of seven mountings and the cylinders are rated at 250 p.s.i. (air) and 500 p.s.i. (hydraulic).

Most recently introduced product on the stand of **Perdeck Solder** (2, Inner) is a solder paint for the tinning of stainless steel and welded surfaces without pre-cleaning.

Plessiflex—a metallic, seamless, flexible hose—figures prominently on 8, Centre. The manufacturers, **Power Auxiliaries,** claim that

National Hall Gallery

Autoflow wet blasting equipment **(Abrasive Developments,** 10, Centre) produces finishes ranging from rough matt to fine satin polish on metals or on plastic surfaces which have to be cleaned, de-burred or de-scaled.

The Kopp variator on 20, Outer, offers a stepless speed variation of 9 : 1 with constant horsepower throughout the output speed range. Models shown by **Allspeeds** include units with (a) free shaft ends, (b) flange mounted motors and (c) built-on reduction gears. Two units in tandem give output speeds of from 110 r.p.m. to 7,000 r.p.m.

On their second stand (7, Inner) **Automotive Products** feature Lockheed-Avery hoses, self-sealing couplings and Purolator filters.

The main feature of **Baldwin** fluid power equipment (2, Centre) is its high quality and extreme reliability making it especially suitable for applications in nuclear engineering. A large number of pilot valves, control units and power cylinders are displayed. All equipment shown can be used with air or low-pressure oil.

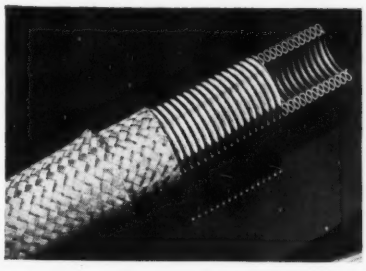
Components which can be easily adapted for handling radio-active material can be seen on 11, Inner **(Bloctube Controls).**

The BG pump shown by **British LaBour Pumps** (23, Inner) is manufactured in a wide range of corrosive-resistant materials. Absence of a mechanical seal or gland packing makes the unit especially suitable for handling radio-active fluids. The BG pump —which has been supplied in large numbers to A.W.R.E. Aldermaston—is vertically-mounted and self-priming.

Brooks and Walker make a special feature of a 16-in. weir cast-steel wedge gate valve on 3, Outer. This valve has Stellite seats and wedge faces. It is operated by a Rotory actuator fitted with a Brookhirst starter.

Pumps by **Drum Engineering** (16, Outer) are claimed to handle liquids of all viscosities.

Fibreglass Pipewrap for the insulation of pipes and trunking can be seen on 11, Outer.



Plessiflex—metallic, seamless hose by Power Auxiliaries.

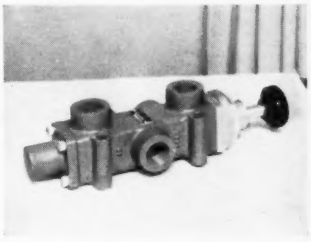
The **Hobson**-A.E.R.E. control system (12, Outer) is designed for heavy-water moderated and cooled thermal reactors similar to Dido. The Hobson honeycomb isotope unit, also developed for Dido, facilitates the production of a large number of isotopes within a limited area: any given container can be inserted or removed without disturbing the remainder. The Hobson-C.R.L. master-slave manipulator, model 7, has a handling capacity of up to 10 lb. per arm.

Organic feed water treatment is one of several subjects dealt with on 13, Inner, by **Houseman and Thompson.** In addition the company provides service facilities for chemical cleaning and de-greasing.

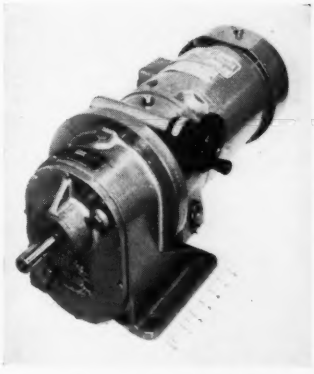
Parallel slide and automatic control valves are being featured on 18, Outer, by **Hunt and Mitton.** The company make a range of packless valves suitable for handling hydrofluoric acid. Where high pressures are involved the company offers a forged steel glanded valve of special design.

"Metals and Nuclear Energy" is the central theme of **ICI Metals Division,** 5, Inner. Various applications of non-ferrous and other metals in nuclear reactors and in heat exchangers, condensers and other plant are exhibited. Some 400 miles of Integron integral steel-finned tubing have now been ordered for nuclear power station heat exchangers. The contribution of the Division to electricity generation is illustrated by a display of condenser tubes in Alumbro and Kunifer together with aluminium alloy and copper busbar and hollow copper conductors for turbo alternators.

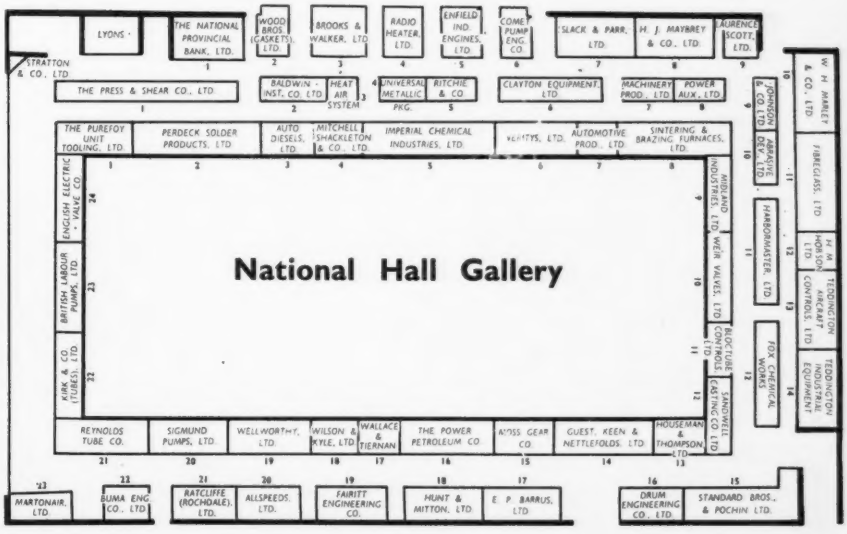
Flanged fittings, fabricated pipework in steel, stainless steel and copper, together with pipework fabricated from rolled and welded steel plate can be seen on 22, Inner. **(Kirk and Co.)**

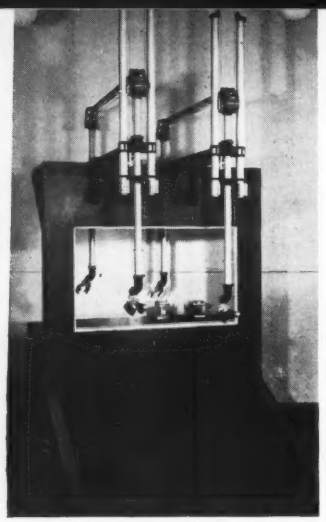


Four-way control valve, ¼-in. bore (Baldwin Instrument).



Motorised reduction gear, ½ h.p. (Allspeeds).





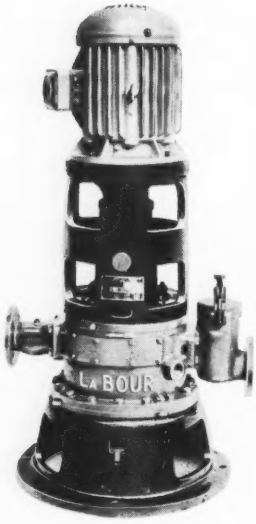
Hobson—C.R.L. master-slave manipulator, model 7.

Plessiflex overcomes problems associated with the conveyance of liquids or gases at high pressures between junctions which are malaligned, move angularly, vibrate or are exposed to high and low temperatures. Power Auxiliaries have supplied to A.E.R.E., Harwell, a 75-ft length of seamless, stainless steel convoluted hose, gas-cooled and built to carry mechanical and electrical cables to a miniature TV camera for the internal inspection of a fuel channel.

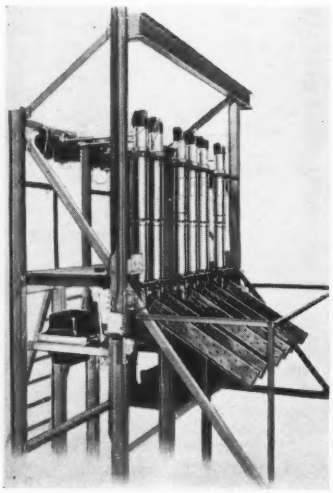
A new induction shaft hardening machine is the focal exhibit of **Radio Heaters** (4, Outer). This unit can produce surface hardening to any depth; it is also possible to harden local zones.

Cold drawn seamless steel tubing, manipulated tubes in steel and aluminium and welded tubular assemblies are displayed on 21, Inner by **Reynolds Tube Co.**

The Cengar air-operated saw shown by **A. H. Ritchie** on 5, Centre, uses ordinary hacksaw blades: it will cut a wide range of materials.



The BG pump is vertically-mounted and self-priming (British LaBour Pumps).



Dido-type coarse control system on test rig (H. M. Hobson).

Sigmund Pumps show on 20, Inner, boiler feed pumps and pumps for handling chemicals.

On 15, Outer, **Standard and Pochin Bros.** have a selection of their centrifugal fans, blowers, air filters and samples of gilled tube.

Teddington Aircraft Controls show, on 13, Outer, a bellows unit of 5 ft 6 in. diameter designed for $\pm 1°$ of angulation at 250 p.s.i. working pressure at 400°C and made from titanium stabilized 18/8 stainless steel. The range of Teddington bellows now extends from $\frac{3}{4}$ in. to 84 in. internal diameter. A feature of these standard units is the use of butt welds rather than lap welds.

A recently introduced dissolved oxygen recorder is being featured by **Wallace and Tiernan** on 17, Inner.

Teddington Industrial Equipment feature on 14, Outer, automatic control equipment for temperature, pressure, humidity, liquid level and speed.

Speciality valves in brass and aluminium in bores ranging from $\frac{1}{4}$ in. to 14 in., as supplied to U.K.A.E.A. are displayed by **Weir Valves** on 10, Inner.

Empire Hall, Ground Floor

As welding gun-specialists, **A.R.O. Machinery** (3, V) show 15 basically different portable spot welders, air or water cooled, hand/air or hydraulically-operated and capable of welding thicknesses from .004 in. + .004 m.s.s. to $\frac{5}{16}$ in. + $\frac{5}{16}$ in.

Bates and Bates are showing, on 6, Y, resistance welding machines developed for use with fully automatic processes, together with a range of control equipment.

F. Bode and Son (2, Y) have added several models to their range of positioners. The Rotilting unit can be manually or power operated; the design ensures that workpieces can be quickly positioned for down-hand welding without complicated balancing procedure.

Where great heat is required, **British Industrial Gases** (7, X) offer a new super heating blowpipe for operation on oxy/propane. The company's new propane regulator is said to be particularly suitable for heavy-duty applications.

On 1, W, **British Oxygen Gases** feature the Argonarc process which was used in the construction of the reactor vessel for Dounreay fast breeder reactor. In addition there is a complete range of Saffire equipment for gas welding, cutting, gouging, heating, flame-cleaning, rivet washing and so on. For profile cutting the company offers the Bison which is capable of cutting up to 12 in. thick.

Courtburn Positioners, on 8, X, specialize in work handling equipment for welding: products include welding platens for setting up heavy fabrications, Courtburn Wilson vices for awkward shaped work and Record clamps for holding pipes for butt welding.

The recently introduced Cromp-Arc J/K Equipment **(Crompton Parkinson,** 3, Y) is a lightweight stud welder for attachments of up to $\frac{3}{8}$-in. diameter in ferrous and non-ferrous metals. Complete with 15 ft of welding and control cable, the unit weighs less than 6 lb; it measures only $7\frac{1}{2}$ in. overall when loaded with a 1-in. stud. The associated controller weighs only 26 lb and measures $7\frac{1}{2}$ in. by $11\frac{1}{2}$ in. by $11\frac{1}{2}$ in.

Dust control equipment by **Dallow and Lambert** on 3, Z, includes wet dedusters, cyclones, Drytube filters, Dustmaster and Drytex unit dust collectors.

Demonstrations of Stellite facing by spray-fusing and illustrations of many different methods of applying Stellite for protecting components against onerous conditions of wear, heat and corrosion are being presented by **Deloro Stellite** on 3, W.

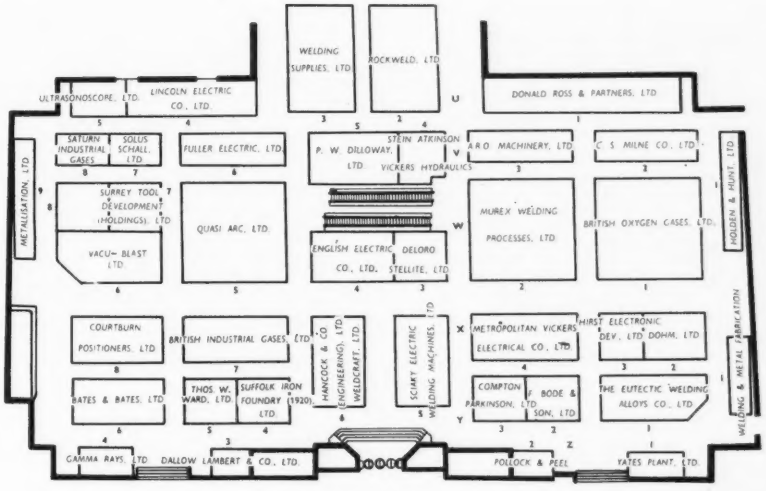
On 4, W, **English Electric** is exhibiting portable welding equipment, including welding regulators, a new welding rectifier and eleven types of electrodes. The new welding rectifier, LWD 350, is continuously rated for hand welding and has been designed and constructed to meet the demand for direct current equipment.

An automatic flash welder for steel pipes with a minimum wall thickness of .168 sq in. and a max. o.d. of 5.25 in. is being displayed by **Fuller Electric** on 6, V. A special arrangement reduces flash inside the pipe.

Following the development of new flux formulæ containing chemicals that improve the bonding of alloys at lower base metal temperatures, **Eutectic Welding Alloys** (1, Y) are introducing a new series of flux-coated rods for torch application to steel, cast iron, malleable iron and so on.

On 4, Z, **Gamma-Rays** show a range of equipment for using radio isotopes industrially. In addition to units for specialized duties the company has developed a range of general-purpose industrial sets.

Empire Hall, Ground Floor



An innovation on the stand is the new Gamma-Rays isotope decay clock for iridium 192. This is shown together with radiation-control instrumentation, illuminators and so on.

A new machine for cutting circular orifices in the hemispherical domes of reactor pressure vessels has been developed by **Hancock and Co.** (6, X). The design enables the machine to cut non-radial holes to close tolerances on formed steel plate of up to several inches thick; provision is made to cut a double bevel and nose preparation for subsequent welding. Hancock also feature a new flame-planing head and a device for the shape cutting of pipes.

For assembly work requiring dust-free conditions **Hirst Electronic** feature on 3, X, a range of air-conditioned benches.

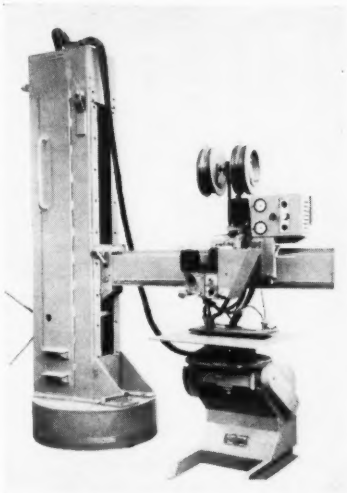
Automatic welding equipment is being demonstrated by **Lincoln Electric** on 4, U. The company are making a special feature of the LAF-2 B.10. Lincolnweld head. In addition there is a representative selection of Lincoln motor generators.

Metropolitan-Vickers display an automatic submerged arc welder for longitudinal welds, on 4, X. The company is also showing a model of a 25-ton electrically operated manipulator.

C. S. Milne and Co. are exhibiting on 2, V, a full range of hand tools comprising welding and cutting blowpipes, descaling and gouging equipment, together with machines for plate profiling, flange cutting and flame hardening.

The new Fortrex 35A electrode shown by **Murex Welding Processes** on 2, W, has been expressly developed for welding extra-thick plate. The weld metal provides extremely high impact properties throughout the whole section of the welded joint at sub-zero temperatures. The new Muramatic automatic arc welder can be used with either the open arc process using continuous cooled electrodes or with the submerged arc process using powder flux. The company are also showing a selection of their test welds on 4-in.-thick plate.

Quasi-Arc feature on 5, W, a very wide selection of automatic welding equipment—including Fusarc, Fusarc/CO_2, Unionmelt and Sigma together with continuous electrode, wire and powder for automatic welding.

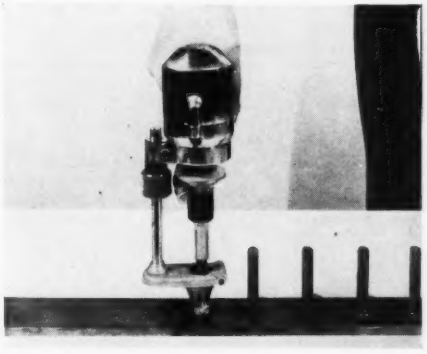


(Above) New Lincolnweld B.10. fully-automatic welding equipment (Lincoln Electric).

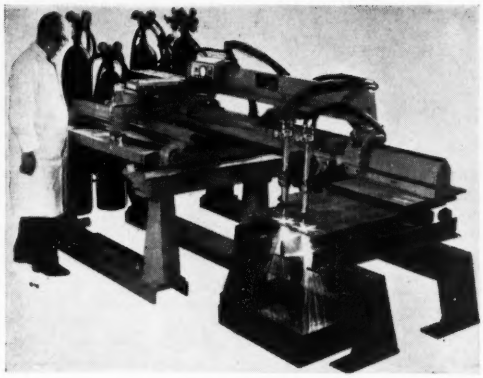
(Above, right) Vacu-Blast high production gun for removal of millscale from flat plate.

(Right) Extreme sensitivity to arc conditions is a feature of the new Autopoint automatic equipment by Rockweld.

(Below) The lightweight Cromp-Arc J/K stud welder (Crompton Parkinson).



(Left) Torch fusing of spray deposit by the new Deloro Stellite process.



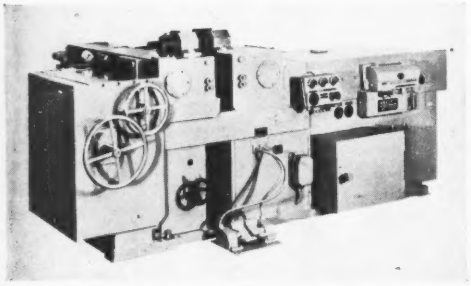
(Right) British Oxygen's Bison oxygen profile cutting machine.

A multi-purpose transformer for both manual and automatic welding, the Autopak, is introduced by **Rockweld** on 2, U. This portable power unit houses components for both double and single operator manual welding or for operating a continuous wire automatic welding head, the Autopoint. Rockweld also market the E.B. root weld insert—a wire of special cross section obtained by machining, cold rolling and cold drawing—which was extensively used for pipe welding on the *Nautilus*.

Twinner turning rolls on 1, U, will handle loads from a few cwt. to 225 tons; the latest design features provide for accurate rotation of the cylinders for welding. **Donald Ross and Partners** are also showing a new self-propelled manipulator for positioning any type of automatic head for internal or external welding.

Two new models of the Saturn-Hivolt surge-injector argon arc welding unit Mk. II and Mk. III are announced by **Saturn Industrial Gases** (8, V). They are developed directly from the Mk. I machine but, among other improvements, have a built-in transformer. These new Saturn-Hivolt machines for welding aluminium alloys and stainless steel have a current range of 30-600 amps from a 42 volts open circuit A.C. supply. Saturn are also introducing four new argon-arc welding torches.

Solus-Schall on 7, V, are featuring non-destructive testing by several different methods—X-rays, gamma-rays, ultrasonic, eddy currents and fluorescent or magnetic penetrants. There are also instruments for electronic micro metrology.



Automatic flash welder, type SVU 786-H, 150 kVA at 50% duty cycle with hydraulic clamping for welding steel pipes (Fuller Electric).

Claimed as the most comprehensive range of power transmission oil hydraulic equipment available in Europe, Vickers-Detroit gear is shown by **Stein Atkinson Vickers Hydraulics** on 4, V.

Some 31 different kinds of Sifbronze oxy-acetylene welding rods can be seen on 4, Y, where **Suffolk Iron Foundry** are featuring examples from their wide range of welding products. The new Demon stainless-steel blowpipe is claimed to cut plate up to 10 in. thick. Of medium weight, the pipe is supplied with two cutting nozzles.

Non-destructive testing equipment in the form of ultrasonic inspection units is exhibited by **Ultrasonoscope** on 5, U. This type of apparatus is extensively used for examining sheet and plate for laminations.

Vacu-Blast mobile dust-free shot blasting machines (6, W) incorporate a unique closed circuit system for abrasive feed and recovery of slag, dust and spent abrasive from the work surface. Each machine provides for separation and cleaning of the abrasive, segregation of the dust and debris with final filtration of dust particles from the exhausted air. Amongst the items of ancillary equipment there is a high production gun for descaling large areas of flat plate.

The Glas-flux process—which obviates the glass-hard residue left by powder flux in bronze welding—is being demonstrated by **Weldcraft** on 6, X.

An oxygen profiler, of advanced design, the OK. Unova, capable of cutting steel plate of up to 12 in. thick, is exhibited by **Welding Supplies** on 3, U. The optical head can be hand-steered for one-off cuts and there is provision for cutting circles, squares, triangles and rectangles without the use of templates. In addition Welding Supplies are demonstrating a magnetic tracing head and an OK. Fotomat photo-electric steering head. The company supplied over 1,000,000 ft of OK. Unitrode for use in welding the heat exchangers at Calder Hall.

Yates Plant feature a range of rotating welding positioners on 1, Z. The company has developed a circumferential backing bar which facilitates pipe welding as the bar also clamps the workpieces together.

Empire Hall, First Floor

Model of a nuclear ship appears on the **Admiralty** stand (9, BB) as part of a feature showing new engineering developments in the Navy.

A 15-in. bore corrugated pipe similar to that supplied to Calder Hall can be seen on the stand of **Aiton and Co.** (7, BB). The corrugations are introduced to provide transverse flexibility. One end of the pipe has a loose Corwel joint; the other is machined for site butt welding. The flexibility of two dissimilar large bore expansion joints in light gauge stainless steel is demonstrated by means of a fatigue testing machine.

Specializing in condenser tube and plate fabrication, the **Birmingham Battery and Metal** is showing a representative range of products on 2, BB. The company make a range of large solid-drawn tubes and several 12-in. bore by 7 s.w.g. and 16-in. bore by 10 s.w.g. Batalbra alloy tubes are shown.

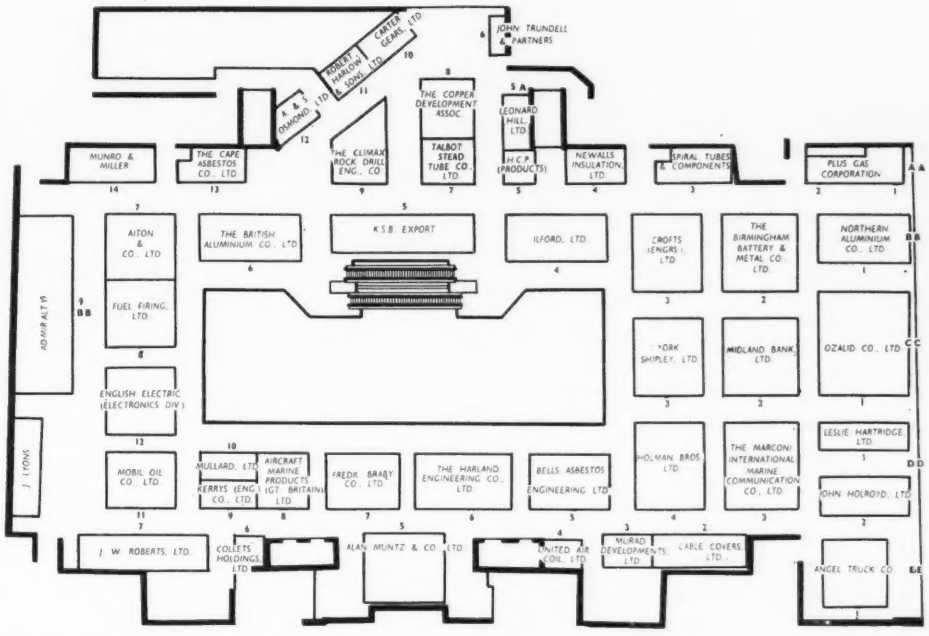
Fredk. Braby's exhibit on 7, DD, includes typical examples of the wide range of fabricated plate and sheet metal work.

Aluminium for nuclear energy applications is shown on 6, BB, by **British Aluminium.** The good low temperature properties of the metal suggest its use for carrying liquid gases.

Talurit wire rope mechanical splices are featured on 2, EE by **Cable Covers.** A 300-ton press for making the splices is being demonstrated.

Rocksil, the only long-fibred rock wool insulation made in the U.K. can be seen on the stand of **Cape Asbestos** (13, AA). This material was used by William Kenyon and Sons for insulating the fast breeder reactor at Dounreay.

A selection from the range of **Carter** hydraulic infinitely variable gears from fractional up to 35 h.p. is displayed on 10, AA. Working and static units, representative of the ten sizes at present manufactured, demonstrate handwheel, remote electrical, lever and hydraulic relay speed controls and complete variable speed drives including different arrangements of electric motors.



Empire Hall, First Floor

Maxam cushioned air cylinders for pneumatic or hydraulic circuits are shown by **Climax Rock Drill and Engineering** on 9, AA.

Hydroflex drives made by **Crofts** are demonstrated on 3, BB. These drives incorporate a vane-type fluid coupling. New worm reduction gears include units of 4 in., 6 in. and 8 in. centres.

Main features of **Harland Engineerings** exhibit (6, DD) is the Ulectriglide submersible pumpset: a high tension version of this type of pump has recently passed the prototype stage.

Many of the exhibits on 11, AA, have been sectioned to show the details of design. The company concerned, **Robert Harlow and Son,** make non-ferrous, cast-iron and steel valves, cocks, mountings and fittings. The range of stop valves includes units with renewable seats, renewable discs or integral seats.

Goodyear positive axial flow pumps incorporating an entirely new pumping principle and suitable for pumping chemicals are shown by **Holman Bros.** on 4, DD.

From their standard range of H-type worm reduction units **John Holroyd** are showing underdriven, overdriven, vertical and double reduction types on 2, DD. There are also some shell castings in Holfor phosphor bronze and in other copper alloys including aluminium bronze and leaded gunmetal.

Although the **Ilford** exhibit on 4, BB is essentially concerned with the Azoflex photoprinting process, the company does make, to special order, nuclear research plates.

Kerry 2 kW Sonorode ultrasonic equipment on 9, DD, is extensively used for machining tungsten carbide, germanium, ceramics and other hard materials.

On 14, AA, **Munro and Miller** have a working model showing the Bellex expansion joint undergoing axial and lateral flexing. These joints, for the transmission of steam, fluids or gasses are made in stainless steel, Monel metal, chrome molybdenum, titanium, aluminium or copper.

A model of Chapelcross atomic power station is one of the main features of 4, AA. **Newalls Insulation** have recently received a contract from Babcock and Wilcox for the thermal insulation of 16 stud tube boilers with integral piping at this new power station. The method of insulating pipes with different types of insulation material is shown, together with a typical length of insulated ventilation trunking.

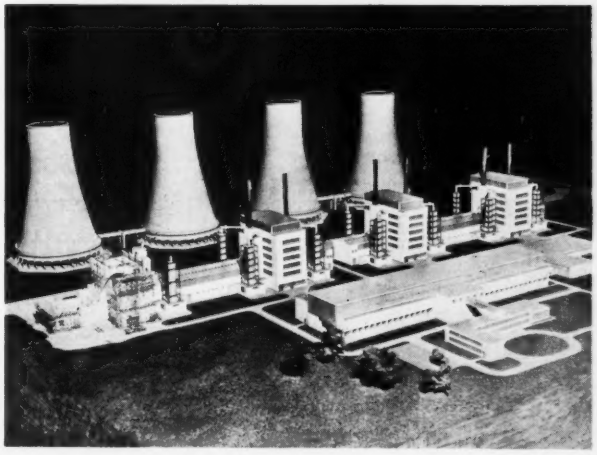
Aluminium has many advantages for nuclear applications and **Northern Aluminium** display on 1, BB, a large structure in Noval aluminium fabricated by The Fairey Aviation Co. for U.K.A.E.A. Other examples of components for nuclear energy applications indicate the good working properties of Noval alloys.

Ozalid drawing-office materials and equipment on 1, CC, are extensively used at atomic research centres and by nuclear consortia.

A new tannating process for the treatment of metal surfaces prior to painting is introduced on 1 and 2, AA, by **Plus-Gas.** The company's dismantling fluid will free seized components or heavily corroded plant.

Heaters for air conditioning and special process plant, together with gilled tubes and coils are to be found on the stand of **Spiral Tube and Components** (3, AA).

Majority of the display by **Talbot Stead Tube Co.** on 7, AA, is concerned with nuclear energy. The company's large-scale facilities for the production of tubes and associated products now play a very large part in nuclear engineering. The company was a major supplier at both Calder Hall and Dounreay. Exhibits include a model of LIDO, reactor control rods, charging standpipes, flanges in stainless steel, tubes in stainless steel and carbon steel, bright drawn bars and wire, together with turned and ground bars.



A model of Chapelcross can be seen on the stand of Newalls Insulation. The company is supplying insulation for the heat exchangers.

RWE 1

The A.M.F.—Mitchell reactor for Frankfurt

Although exact details of the core, such as the overall enrichment, are not yet finalized, engineering design of the RWE 1 power station is completed and ground was broken at the site in August. The reactor is an enriched uranium closed cycle boiling light water system employing natural circulation.

THE consortium composed of A.M.F. Atomics Inc. of New York, and Mitchell Engineering Ltd., of London, in association with Siemens-Schuckertwerke have begun construction of a 15 MW nuclear power station at Dettingen near Frankfurt-Main. The maximum output of the plant is guaranteed at 16.2 MW but recent legislation in Germany has limited the operational output to 15 MW. Basic design comprising the feasibility study and the nuclear physics is the responsibility of A.M.F. and this company will also supply the core of the reactor. Detailed engineering design and construction of the reactor vessel, heat exchangers, the associated primary circuit, fuel handling, containment, etc., is the responsibility of Mitchell Engineering, whilst the secondary steam side turbo-alternators, etc., will be handled by Siemens-Schuckertwerke.

The reactor is a closed cycle, boiling, light water system using natural circulation and transferring the heat to a secondary steam circuit feeding the turbines. It is fuelled by a mixture of enriched uranium and thorium, the effective active volume being 5 ft diameter by 5 ft high.

The core is contained in a stainless-steel clad, carbon-steel pressure vessel with bolted ellipsoidal top closure. Standpipes at the bottom allow entry for the control rods which move out of the core in an upwards direction. The reactor vessel is surrounded by a 5-ft concrete shield and the heat exchangers are assembled around this inner shield together with the ancillary piping, demineralizing plant sub-coolers, etc., which are enclosed in a further 2-ft concrete shield. The whole structure is contained within a steel vessel with cylindrical sides and hemispherical ends, thus the whole of the primary side and the reactor is shielded and contained. The containment vessel is interred up to a level corresponding roughly with the top of the reactor vessel. Provision is also made within the containment for fuel element storage, and for primary water cooling and retention should the circuit leak (Fig. 1).

Reactor Vessel

The reactor vessel, which is 26 ft high and 7 ft 6 in. i.d., is of 4-in. carbon steel clad with ¼-in. stainless steel of a type similar to SA312 type 304L. The top closure of the vessel is retained by 40 4-in. studs round the flange of thickness $10\frac{7}{8}$ in. and overall diameter 10 ft 4 in. Three 6-in. locating rods fix the orientation and two annular stainless steel covered gaskets effect the seal. The interspace is scavenged as a seal check (Fig. 2).

The core is held in the reactor vessel by a stainless-steel basket which is supported from a groove in the vessel at the parting line with the head. Its lower end is supported on pads in the reactor vessel wall. It is designed to allow for the differential thermal expansion between the reactor vessel and the basket, and still maintain adequate alignment with the control rods. The basket acts to some extent as a thermal shield.

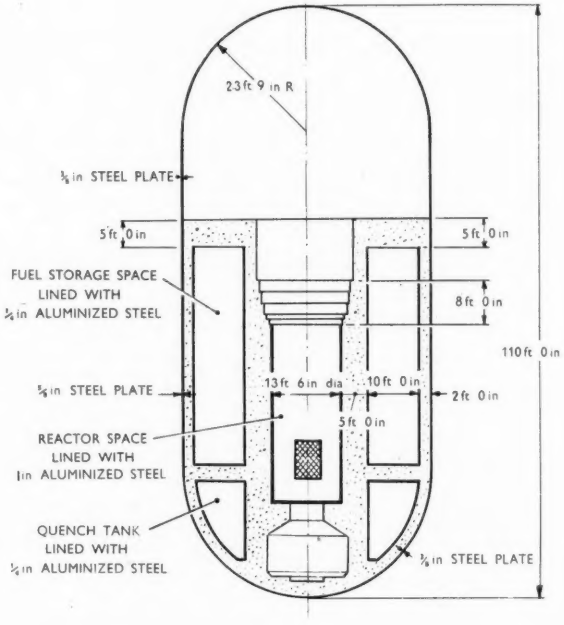


Fig. 1.—Shielding and containment of the reactor vessel and primary steam circuits. The lower half of the shell is further screened by the ground.

Core Structure

Each fuel element, of which there are 3,920 in 80 assemblies, is comprised of a 0.485 in. o.d. Zircaloy can of 0.03 in. wall thickness containing slugs of thorium oxide cermet and uranium oxide cermet. The uranium is enriched to about 10% to give a cold, unpoisoned excess reactivity of 6%. Flattening across the core and reactivity is adjusted by changing the ratio of uranium slugs to thorium slugs. Being ceramic the conductivity of the fuel elements is low and the maximum internal temperature is, therefore, high. The exact value will depend upon the final

The World's Reactors

No. 13—RWE 1

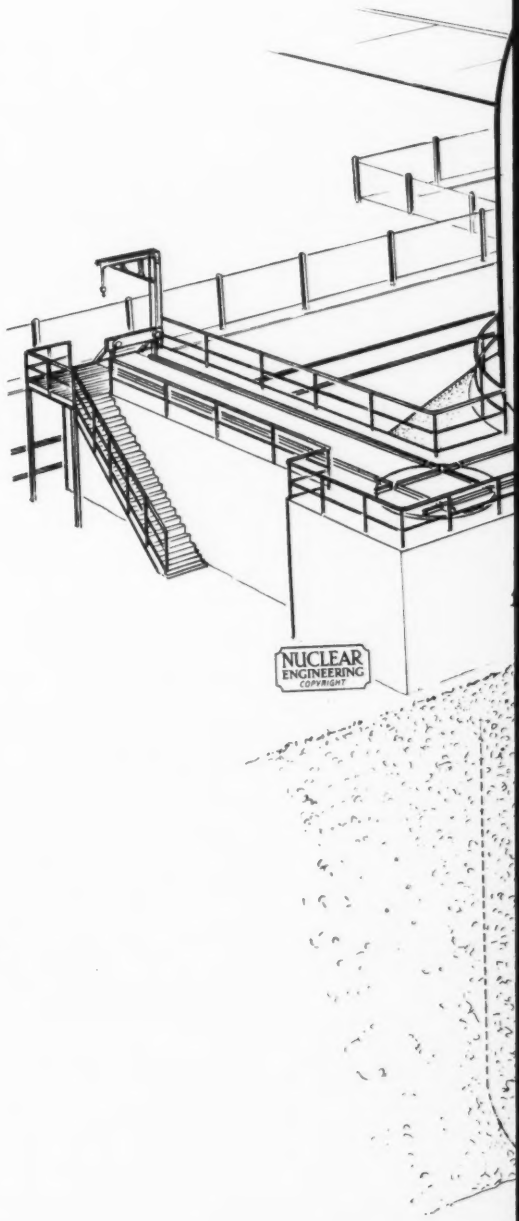
(Rheinisch-Westfalisches Elektrizitatswerk A.G.)

DESIGN AND CONSTRUCTION

KEY

REACTOR CONTAINMENT

1. Reactor vessel
2. Fuel elements
3. Control rods (16)
4. Heat exchangers (4)
5. Sub-coolers (4)
6. Feed tank (2)
7. Feed pump (2)
8. Quench tank dump pumps (2)
9. Demineralizing column
10. Regenerative feed heater
11. Purification loop cooler
12. Reactor space pressure relief pipe
13. Quench tank cooling coils
14. Reactor space cooling coils
15. Quench tank (steel lined)
16. Sump
17. Used fuel storage space (steel lined)
18. Maintenance access
19. Maintenance access closure
20. Top shield
21. Steel pressure dome
22. Access door
23. Sheet steel piling
24. Steam separator
25. Demineralized water supply tanks (2)
26. Soil backfill
42. Reserve ring main



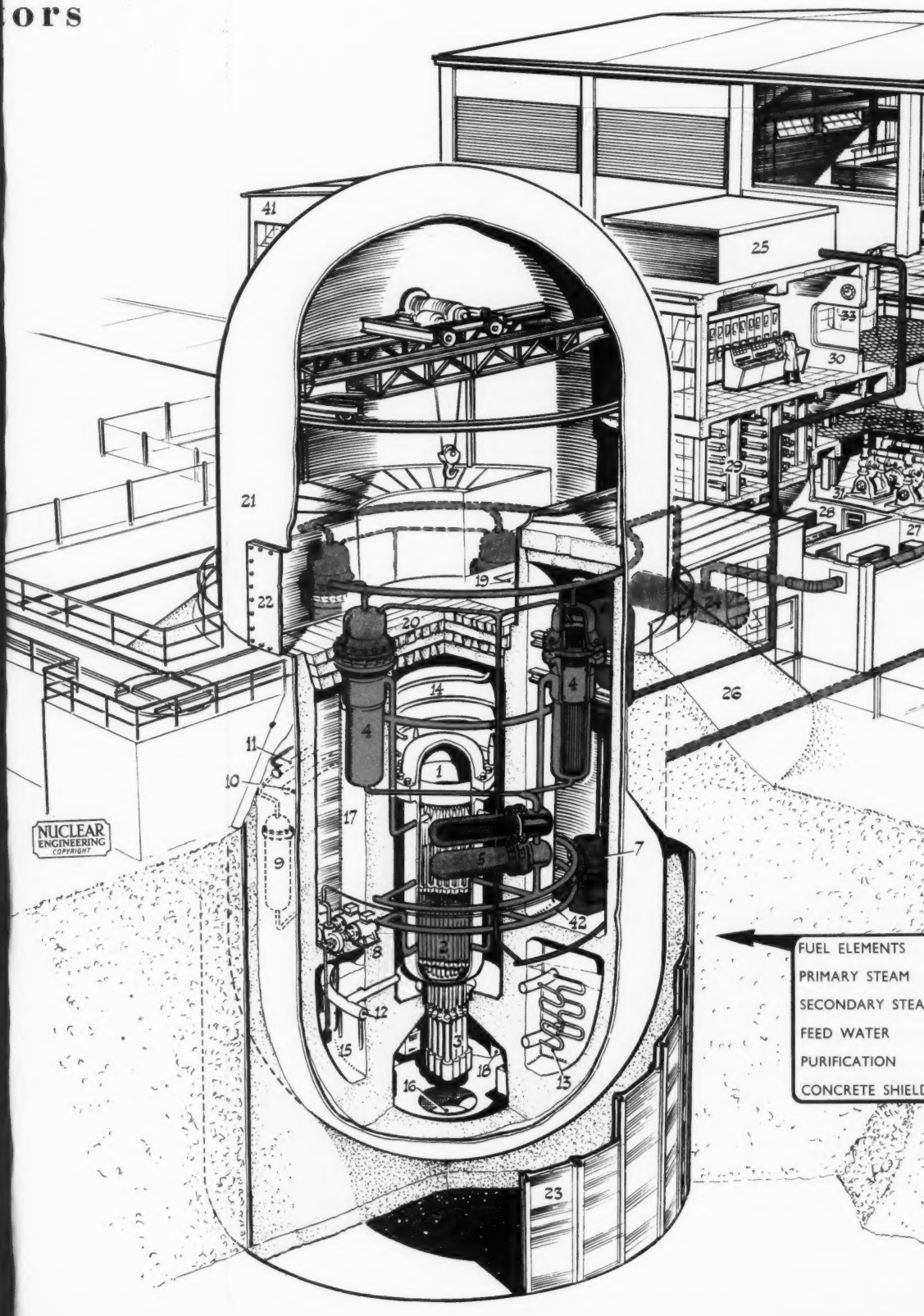
TURBINE HOUSE

27. Battery room
28. Switchgear room
29. Cable room
30. Control room
31. Feed water pumps (2 electro, 1 turbo)
32. Feed water storage tank
33. De-aerator
34. L.P. preheater
35. H.P. preheater
36. Vacuum preheater
37. Condenser
38. L.P. turbine
39. H.P. turbine
40. 15 MW generator
41. Administrative buildings and water treatment plant

DESIGN AND CONSTRUCTION

A. M. F. Atomics Inc. New York.
Mitchell Engineering Ltd. London.
Siemens Schuckertswerke Erlangen.

ors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FEED WATER
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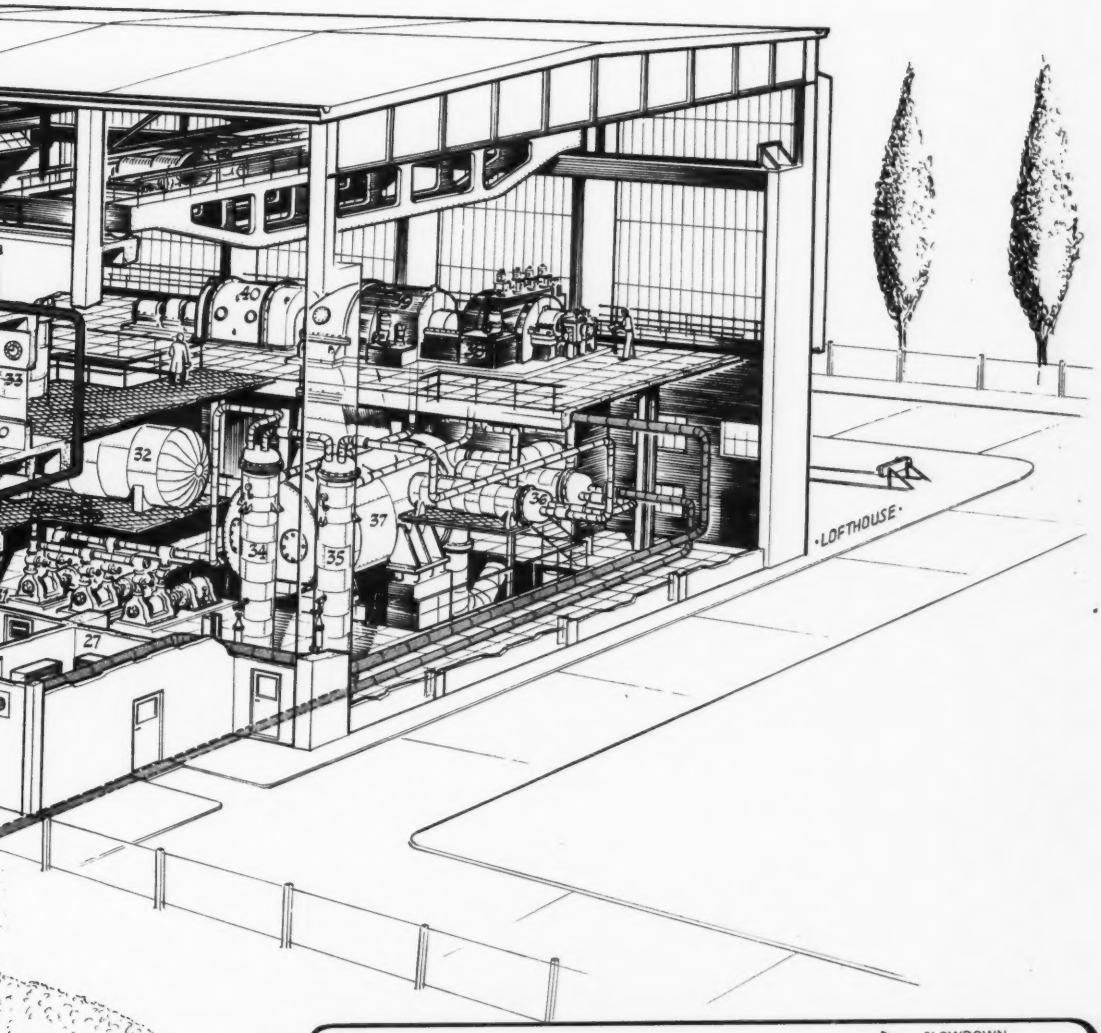
CONCRETE SHIELD



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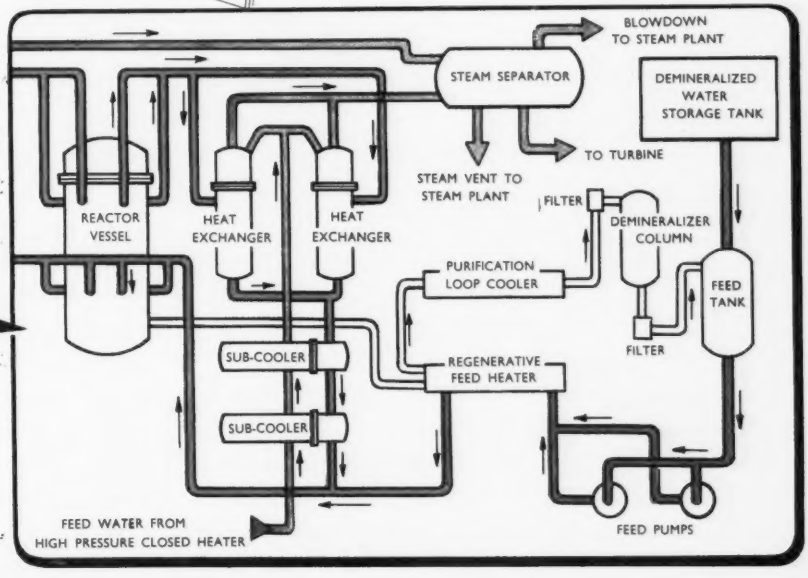

The World's Reactors

No. 14 RWE 1

TYPE :	Boiling water reactor.
PURPOSE :	Power production.
LOCATION :	Dettingen, near Frankfurt-Main.
OPERATION :	Site clearance begun : Aug., 1957. Commissioning : Oct., 1959.
RATING :	Reactor : 58 MW (heat). Guaranteed net output : 16.2 MW. Installed capacity : 17.13 MW.
FUEL :	Thorium oxide (75%), enriched uranium oxide (25%). Max. fuel temp. $>$3,200°F. Max. heat flux $>$450,000 BTU/h,ft^2. Average heat flux $>$114,000 BTU/h,ft^2.
CORE :	80 assemblies, each of 49 elements, in 0.078 in Zircaloy frame. Active volume : 5 ft dia. × 5 ft high. Weight (including cladding) : 6 ton. Excess reactivity : 6%.
FUEL ELEMENTS :	Cylindrical : 5 ft high × 0.425 in dia. Cladding : zirconium alloy, 0.03 in thick. Zircaloy tubes filled with short ceramic slugs. Riser sections : 5 ft high. Max. fuel surface temp. $<$800°F. Max. cladding surface temp. $<$565°F.
MODERATOR :	Light water.
CONTROL :	16 cruciform rods, in two groups (12 safety and 4 control). Blade span : 11 in, thickness $\frac{1}{4}$ in. Stroke : 4 ft 6 in. Material : 4 inner rods hafnium, 12 outer rods borated stainless steel. Electro-mechanical drive from bottom of reactor.
PRESSURE VESSEL :	26 ft high × 7 ft 6 in i.d. Wall thickness : 4 in. Material : SA 212 B. Internal cladding : $\frac{1}{4}$ in stainless steel, SA 312 type 304 L.
COOLANT :	Boiling light water, natural circulation. Inlet temp.: 400°F. Outlet temp.: 533°F. Pressure (saturation) : 900 p.s.i.g. Flow (at 58 MW) : 241,000 lb/h. Av. vol. steam in core : 13%. Max. solids conc.: 2 ppm. Purification bleed : 10 gal/min.
BOILERS :	4 in number, type C.T. Secondary steam formed in annulus between $\frac{1}{2}$ in o.d. carbon steel tube and 1 in o.d. 16 s.w.g. stainless steel tube. Dimensions : 3 ft 3 in i.d., length below tube plate : 14 ft, above tube plate : 3 ft 6 in. Vessel : Carbon steel SA 212 B, $1\frac{3}{4}$ in thick over main length. Cladding (primary steam side) : $\frac{1}{8}$ in type 304 stainless steel. Tube plate : 212 B carbon steel, clad on lower side with $\frac{1}{8}$ in type 304 stainless steel.

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SECONDARY COOLANT :	Steam to turbine. Flow at max. rating : 224,000 lb/h. Inlet temp. sub-coolers : 350°F. Outlet temp. at T.S.V.: 497°F. Pressure : 600 p.s.i.g.
ALTERNATOR :	17.13 MW. 6 kV, 3 ph, 50 c/s.
SHIELDING :	1 in steel thermal shield in vessel, and concrete. Sides 5 ft thick round vessel, Additional 2 ft round primary circuits. Top : 8 ft over vessel, 5 ft over primary circuits. Bottom : 1 ft lead below p.v. Lining : 1 in aluminized steel in reactor space, $\frac{1}{4}$ in aluminized steel in quench tank and fuel storage space.
CONTAINMENT :	Cylindrical steel vessel, hemispherical ends. Plate thickness : side $\frac{3}{8}$ in, ends $\frac{3}{8}$ in. Overall dimensions : 47 ft 6 in dia. × 110 ft high.

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. *BEPO* (*April*, 1956)
No. 2. *CP5* (*May*, 1956)
No. 3. *NRX* (*June*, 1956)
No. 4. *DIMPLE* (*August*, 1956)
No. 5. *ZEUS* (*September*, 1956)
No. 6. *CALDER HALL* (*October and December*, 1956)
No. 7. *RUSSIAN 5 MW* (*November*, 1956)
No. 8. *DIDO* (*January*, 1957)
No. 9. *THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION* (*February*, 1957)
No. 10. *BERKELEY POWER STATION* (*March*, 1957)
No. 11. *BRADWELL POWER STATION* (*April*, 1957)
No. 12. *DOUNREAY FAST REACTOR* (*June*, 1957)
No. 13. *EBWR* (*July*, 1957)

composition of the fuel but will not be greater than 3,200°F. The rod-type ceramic fuel has been chosen because of dimensional stability under irradiation, and inertness to chemical attack by de-gassed steam and water. The slugs are completely isotropic with respect to processing and fabrication history and undergo no allotropic phase changes up to melting point. Temperature at the interface with the zirconium cladding will be less than 800°F. There is no metallurgical bond between the slugs and cladding but the operational pressure in the reactor ensures good mechanical contact.

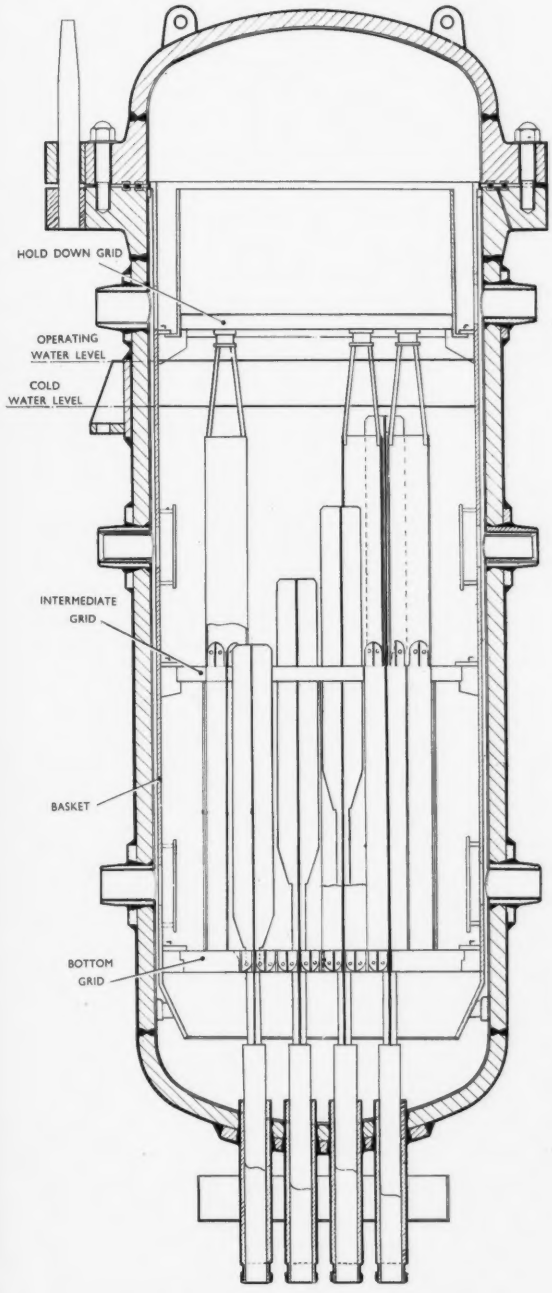


Fig. 2.—Reactor pressure vessel showing position of fuel assemblies with risers and cruciform control rods operated from below. Top closure is located by three 6-in. pins and secured by 40 4-in. studs.

The maximum surface temperature of the cladding will be less than 565°F when the reactor is running at the full power of 58 MW (heat). In this condition, at most, 13% by volume steam will be formed in the cooling channels.

The cans are provided with tabs which are welded to Zircaloy cross members which in turn are welded to a Zircaloy and stainless-steel frame to form an assembly.

Risers 5 ft high are mounted over groups of four assemblies, each riser fitting against the end fitting of the fuel assemblies which pass through the intermediate grid with small clearance. The top of the riser terminates in a pin that locates in a hold-down grid plate. Springs may be used between the riser and the hold-down grid, to assist gravity in holding down the riser. The riser must be free to move up and down in the hold-down grid to allow for differential thermal expansion between the Zircaloy core and the stainless-steel basket. The riser fits with a small interference over the cruciform end of the fuel assembly, which produces a spring effect to hold the fuel assembly against the intermediate grid bars and away from the control rods. The risers also form a shroud and guide for the control rod. Some of the risers on the periphery will serve less than four fuel assemblies.

Three grids are used to support the core. The weight of the fuel assemblies is taken by the bottom grid which is attached to the core basket. The intermediate grid locates the top end of the fuel assembly and the bottom of the risers and can be left in place and the fuel assemblies pulled through during refuelling operations. It is supported much the same as the bottom grid. In this case the side plates of the fuel assembly end fitting sit against the grid bars instead of the cruciform nose in the bottom grid.

The hold-down grid locates the tops of the risers. It is supported at four points like the other grids, but it must be removed for refuelling. The hold-down lugs are therefore designed for easy release from a remote station.

Control Rods

Control of the reactor is carried out by 16 cruciform-shaped control rods operated from the bottom of the reactor, by an irreversible drive system. A rotary type seal is used to minimize leakage of the primary coolant from the reactor vessel. The four inner control rods will be used for operational control and the 12 outer rods for start-up and shut-down. A scram signal results in the control rods being released by the drives, and springs force the control rods down into the core. Provision is made for deceleration of the control rods towards the bottom of their travel. An emergency boric acid injection system is also provided should there be complete failure of all forms of control.

Steam Circuits

Condensate from the four heat exchangers passes through sub-coolers and enters the reactor from the ring main through four 6-in. pipes. Baffles are provided on the inside of the vessel. The water flows down into the bottom of the vessel and up through the channels and risers. The 8-in. outlet pipes are connected in pairs, each pair feeding two heat exchangers. A 10 gal/min feed is taken from the bottom of the reactor vessel through a regenerative feed heater to cooler and then through a demineralizing column and filter to a feed tank (all within the containment shield). Return is through the regenerative feed heater to the primary inlet main.

Feed water for the secondary steam side is heated in low and high-pressure steam heaters, passes through the sub-coolers from which it enters the heat exchangers at nearly saturation temperature. Superheated steam from the heat exchangers passes through a steam separator and from there to the turbine. Additional drying may be included.

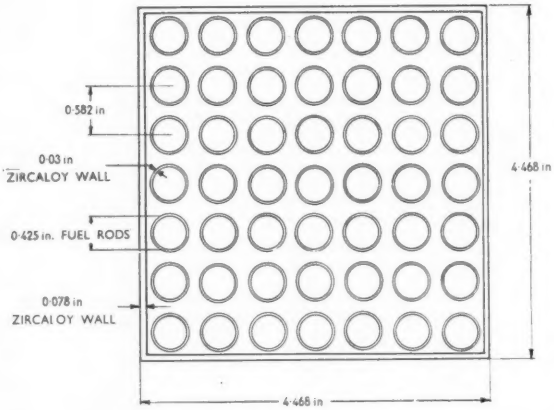


Fig. 3.—Cross section of fuel assembly. Fuel rods comprise a mixed array of uranium and thorium ceramic slugs.

Heat Exchangers

These are of the "C.T." type where the primary steam enters the shell side below the tube plate and condenses on the outer surface of the tubes. Condensate flows from the lower head of the heat exchanger.

The tubes are arranged in a concentric manner, each outer tube being 1 in. o.d. stainless steel 16 s.w.g. thick expanded and welded into the main tube plate. The lower end of this tubing is sealed off. Inside each 1-in. tube is a ½-in. o.d. carbon-steel tube which ends approximately 1 in. above the closed end of the outer tubing and passes right through the main tube plate and is finally expanded into an auxiliary tube plate in head portion of exchanger.

Feed water from the sub-coolers, at saturation temperature, enters the head of the exchanger through a 3-in. nom. bore pipe and is distributed to all the tube bundles, flowing down the central tubes.

Steam is formed in the annulus, rises up the tubes and separates in the steam chest at the upper end of the exchanger. To assist separation a simple form of dryer will be fitted into the head.

The whole of the shell (carbon steel SA212B or equivalent) is lined with ⅛-in.-type 304 stainless steel to prevent corrosion, the tube being of similar construction. The inlet of the primary steam is an 8-in. pipe and the primary condensate outlet a 4-in. pipe.

The primary and secondary side of the heat exchanger has a design pressure of 1,200 p.s.i.g. in order that in the event of a tube failure the heat exchangers can be sealed off on the secondary side of the system to allow the plant to continue operating at reduced load.

Sub-coolers

The arrangement of the heat exchangers in the general layout of the reactor plant will be such that for natural circulation two sub-coolers will be coupled in series, and these in turn coupled to a pair of heat exchangers.

Sub-coolers will be of the hairpin type; inside diameter of the shell approximately 2 ft 6 in. The shell will be manufactured from carbon steel SA212B or equal and will have a thickness of 1⅜ in. The parallel length of the sub-cooler on the secondary side will be 9 ft 6 in. and the end will be closed by a standard dished end. The head of the unit will be bolted to the main body and this will have a type 304 stainless-steel lining to prevent corrosion in the primary loop.

The tubing will be manufactured from type 304 stainless steel and each tube will be 1 in. o.d., the pitching in the tube plate being 1¼ in. triangular pitch.

One 8-in. inlet and one 8-in. outlet branch will be fitted into the head for the primary loop. On the secondary side the inlet and outlet branches for the feed water will be 4 in.

Operation

The station, which will be the first plant in Europe designed primarily for power production, will be operated by the constructors for six months before finally being handed over to the electricity authority.

Le Réacteur Mitchell-A.M.F.

En tant qu'entreprise en commun, A.M.F. Atomics Inc. de New York, Mitchell Engineering Ltd. de Londres et Siemens-Schuckertwerke d'Allemagne sont en train de construire une Centrale d'Energie Nucléaire de 15 MW à Dettingen près de Frankfort-s/Main (cette centrale fait l'objet du dépliant de ce numéro).

Le réacteur est du type à eau bouillante à cycle fermé et à la puissance nominale maximum prévue de 58 MW (chaleur) il produit de la vapeur à une pression de 63.5 kg/cm² à 110,000 kg/h. La vapeur saturée passe dans quatre échangeurs de chaleur qui produisent de la vapeur pour la turbine à une pression de 42.4 kg/cm², la température à la vanne d'arrêt de la turbine étant de 285°C, et le débit de vapeur de 100,000 kg/h au rendement maximum de 16.2 MW(E).

Mitchell-A.M.F.-Reaktor

Als Gemeinschaftsunternehmung bauen A.M.F. Atomic Inc., New York, Mitchell Engineering Ltd., London, und Siemens-Schuckertwerke AG., Deutschland, ein 15 MW Kernkraftwerk in Dettingen bei Frankfurt a/M. (Dieses Werk ist das Thema des Auszuges aus dieser Ausgabe.)

Es handelt sich um einen Siedewasserreaktor mit geschlossenem Kreislauf, der bei voller Nennleistung von 58 MW (Wärme) 110,000 kg/h Dampf von 63,5 kg/cm² erzeugt. Der Sattdampf wird durch vier Wärmeaustauscher geleitet, die den Turbinendampf von 42 atü erzeugen. Die Temperatur am Turbinenabsperrventil ist 258°C, und bei der Höchstleistung von 16,2 MW(E) beträgt der Dampfdurchsatz 100,000 kg/h.

El Reactor Mitchell-A.M.F.

Como una empresa mancomunada la firma A.M.F. Atomics Inc., de Nueva York, la Mitchell Engineering Ltd., de Londres y Siemens-Schuckertwerke de Alemania está construyendo una Central de Fuerza Nuclear en Dettingen, cerca de Frankfurt-Main (esta Central forma el objeto de la hoja inserta en este número).

El reactor es del tipo de agua hirviente y ciclo cerrado y al regimen diseñado máximo de 58 MW (calor) genera vapor a una presión de 63,5 kg/cm² a 110,000 kg/h. El vapor saturado pasa a cuatro cambiadores de calor que generan vapor para la turbina a una presión de 600 p.s.i.g., siendo que la temperatura en la válvula de detención es de 258° C, y el flujo de vapor de 100,000 kg/h al rendimiento máximo de 16,2 MW(E).

REMOTE HANDLING

3. Alpha-Active Materials

By W. K. CURTIS
(*Remote Handling Group A.E.R.E. Harwell*)

Previous articles in this series have given an introductory survey (May) and information on remote viewing (August). This article deals with the problems of handling alpha-active materials which, while not requiring heavy shielding nevertheless present considerable hazards and require complete containment and special precautions in the decontamination of the equipment.

ALTHOUGH alpha particles cannot penetrate even quite thin materials, such as the skin, they must not find their way to the inside of the body by breathing, ingestion, or through cuts.

The main requirement in the design of equipment is, therefore, the complete containment of alpha-active materials on which work has to be carried out, and this can be generally satisfied by the use of glove boxes, leak tight, constructed within closely specified limits and operated under reduced pressure so that any leakage takes place inwards. Given leak-tight shells, the major problem has been to find means of:—

1. Sealing window panels and frames round openings.
2. Changing gloves without leakage.
3. Ingress and egress without leakage.

This applies to all kinds of boxes, from the smallest, like the Harwell Mark III, which is only 2 ft 3 in. long, and 1 ft 4 in. deep, to those chambers which are not boxes in the true sense, but rooms in a building such as that which houses the electromagnetic separator " Hermes."

The integrity of sealing demanded will depend on the kind of materials handled and on the personnel. For example, liquids already contained in tubes, flasks and chemical equipment are safe unless spilt. If a spill inside a box can be cleaned up then containment inside the box is fairly simple; quite different, in fact, from an operation where active powder can be spread about, perhaps by the very operation itself, say in powder compressing.

Another point to bear in mind is that where toxic matter must be handled in an inert atmosphere, any leak will dilute this atmosphere; so that additional care must be taken with the sealing.

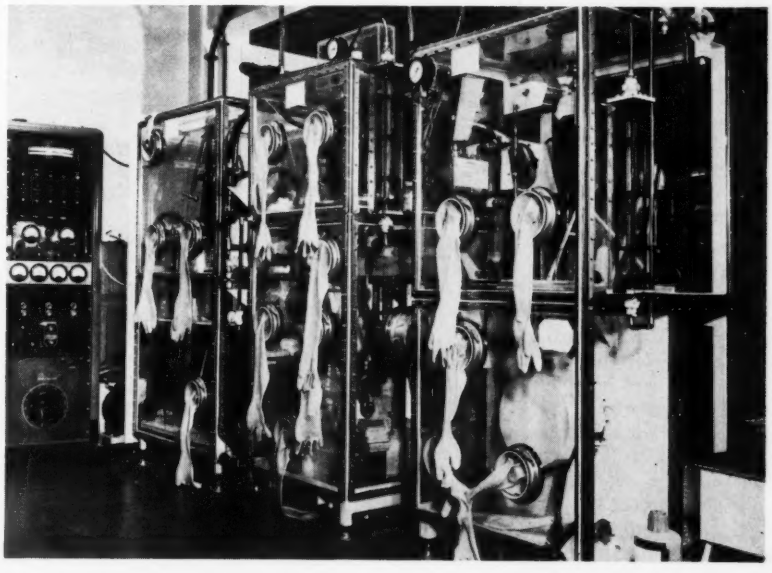


Fig. 1.—A suite of three double-chamber glove boxes, interconnected.

Free-standing Boxes

The following descriptions deal with the design and construction of free-standing boxes to quite high degrees of leak tightness. The designer must take into consideration fabrication and general economics of the work; fire hazard; needs for decontamination; easy production of good sealing faces; weight and size for portability and lastly, disposal.

Main Structures

Early boxes were made of timber, usually of thick plywood, jointed at the corners with openings cut for window panels, gloves and transfers. These proved quick to make, economical, easily disposed of, and satisfactory for low dilute levels of activity, but difficult to decontaminate and not suitable for concentrated solutions.

Small boxes can be made wholly of Perspex, cemented and screwed. An extremely easily disposable box is an envelope made of transparent p.v.c. and supported inside a frame such as " Jencon." The p.v.c. is welded up by the radio frequency welding process and secured to a $\frac{3}{8}$-in. thick Perspex front panel which takes gloves, transfer flanges, etc. (Fig. 2).

One of the later developments is the use of moulded shells of resin-impregnated glass fibre. Little practical experience of their use is at present available, but they have many advantages. The window panels may be moulded in, saving gaskets and seal joints and means of securing. The inside can be smooth and well rounded for easy decontamination and the material itself is highly resistant to corrosion. Where fixings are required, tapped blocks or studs can be moulded in.

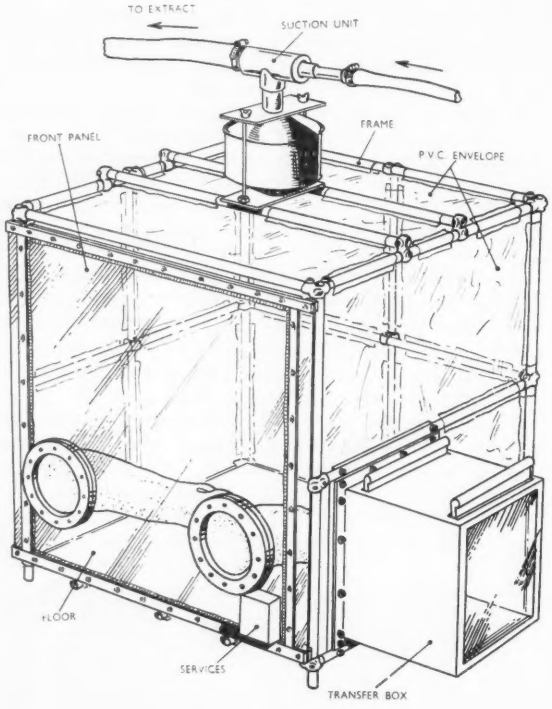
Aluminium or an aluminium alloy is another material which can be used, and in a few instances stainless steel may be considered desirable. Generally, however, mild

steel, suitably treated, is effective both from corrosion resistance and ease of decontamination.

The design of shells has followed along two main lines. Formed sheet welded up (see Fig. 3) and welded angle framework (see Fig. 4). The formed sheet box known as the Harwell Mark I now manufactured commercially, is economical, and what is equally important, is readily available. It has proved itself over a number of years adaptable, comfortable and efficient.

The main shell is formed from sheet mild steel, bent at a large radius, which provides smooth inside corners and easy cleaning. The openings cut in the faces are finished with rounded corners. The Perspex window panels have the same contour as the box, are slightly smaller in size, and are held in place by a sealing strip known as "Claytonrite" (Fig. 6). It is proving leak tight when fitted to special

Fig. 2.—(Below) General arrangement of disposable p.c.v. box.
Fig. 3.—(Right) The Harwell Mark I free-standing box.

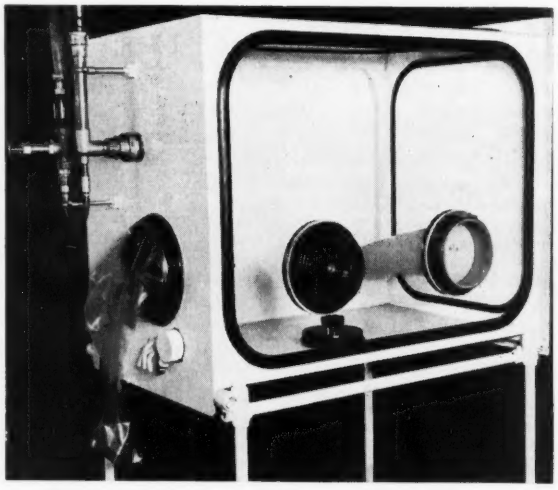


instructions. The joint at the ends of the sealing strip and the keying strip are arranged to finish diametrically opposite, and care must be taken to cut all ends square, the ends of the sealing strip being treated with a sealing compound.

Under test, panels of 30 in. by 20 in. have been known to stand firm against a pressure of 24 in. w.g. Where the load has been raised enough to blow a panel in, the sealing strip and panel were found to be intact and replaceable although in cases where high differential pressures are possible the stud and nut panel fixing should be used.

The Mark I is supplied with an internal filter which can be changed without exposing it to the laboratory atmosphere. The depression is obtained by a compressed air operated ejector.

Services into the box are provided by a three-pipe entry for ventilation air or suction or inert gases when required.



An electric terminal box with a stuffing-type gland allows electric cables to be taken through (see Fig. 3).

The type of box constructed from angle steel with studs for securing panel is shown in Fig. 4. These were originally designed for apparatus involving heavier duty and into such boxes have been put lathes, small machine tools and similar equipment. They are extremely sturdy and adequate for the heaviest work. In those cases where dilution of inert atmospheres must be avoided this is the type of box chosen, because lower leak rates can be obtained. Fig. 5 shows a type of panel fixing.

Ventilation

Stress has been laid on the need for low leak rates and something in more detail must now be said about atmospheres and ventilation. These boxes are expected to operate at depressions of from $-\frac{1}{4}$ in. to -2 in. w.g., and the general test for leaks is 0.5% to 0.05% volume per hour at a pressure of 4 in. w.g. according to the type of work. Under working conditions the depression may be obtained by using an electric centrifugal fan controlled by a resistance or a compressed-air ejector according to the cost of the pump or the availability and economics of the power supply. With large assemblies of boxes it is easy to overload the power supply. One advantage with ejectors is the fact that they are gas tight to the atmosphere with no moving parts and practically unlimited life, whereas electric motors need servicing and may leak along the spindle when switched off.

Great care must be taken with all pipe lines into or out of boxes. Non-return valves are fitted at all points where back pressure might drive contamination into otherwise clean areas, e.g. argon feed from purifiers and even from gas cylinders, because it must be remembered that the connecting hose carrying the gas will one day need to be worked on or replaced, and the cleaner it is inside, the easier it is to deal with. The extract from boxes is taken through filters and piped into building extract ducts. These ducts in turn are pumped by the ventilator fans in the building and the extract drawn through filters. The filters currently fitted are pleated fibre-glass film with a pressure drop of 0.5 in. w.g. at 3 ft^3/min flow.

To facilitate changing in some cases it is worth while to put two filters in parallel, with shut-off valves to each, enabling the operator to run one while the other is changed, with no fear of unfiltered extract entering the ducting.

It has been found that it is a help to use self-sealing

connections and that although they are not completely satisfactory, having been designed for a different set of conditions, they do assist containment considerably. It is usual to wrap them in a loose p.v.c. sleeve securely taped to the pipework and after the disconnection is made to weld across the middle and cut apart as described in Transferring. This assists the mobility considerably. In many cases it is found that the active extract system in the building is sufficient to reduce the pressure to the required amount but where this cannot always be relied upon, auxiliary extractors are fitted. Boxes will hold their pressures for periods in the order of weeks when closed down.

Inert Atmospheres

In many instances inert atmospheres are necessary. Once the box has been purged and filled:—

1. The work may be carried out under static depressed conditions.
2. Ventilation may be obtained in a depressed box by bleeding in small quantities of gas.
3. Gas may be taken out, purified, and recirculated.

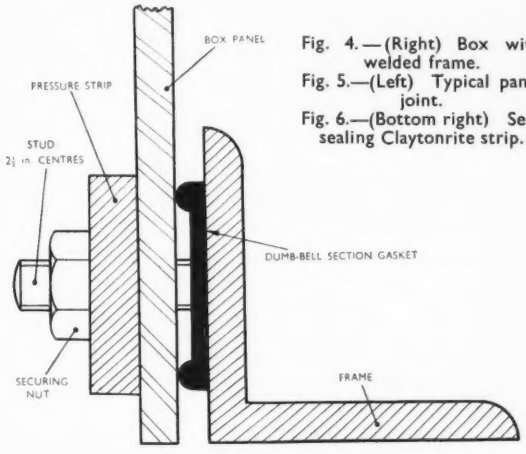


Fig. 4.—(Right) Box with welded frame.
Fig. 5.—(Left) Typical panel joint.
Fig. 6.—(Bottom right) Self-sealing Claytonrite strip.

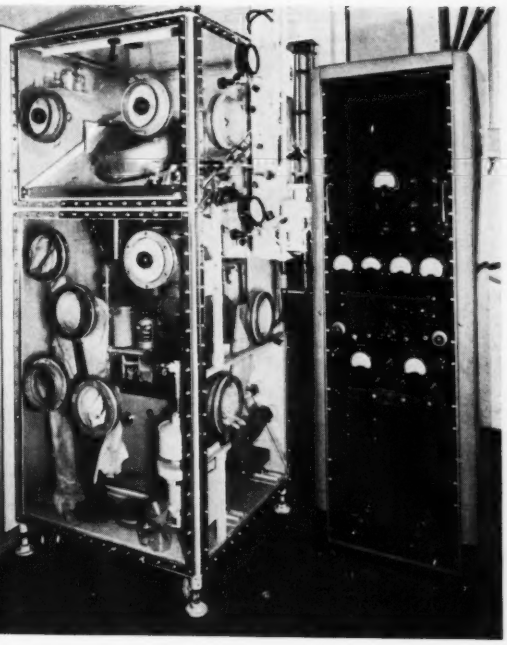
The first may be useful and economical when long setting-up time precedes a short-run experiment. For cooling purposes or removal of fumes the second may be used, but for long runs with the more expensive gases, such as argon, a purification plant is most satisfactory, especially in such cases where high purity is essential. Quite elaborate methods have been devised for control of pressure and flow rates, but experience has shown that magnetic valve systems are not necessary for ordinary use, and close control can be obtained from a simple control valve and flow meter. To prevent leak along the gland, valves having a diaphragm are chosen and a similar approach has to be made to the choice of all ancillary equipment.

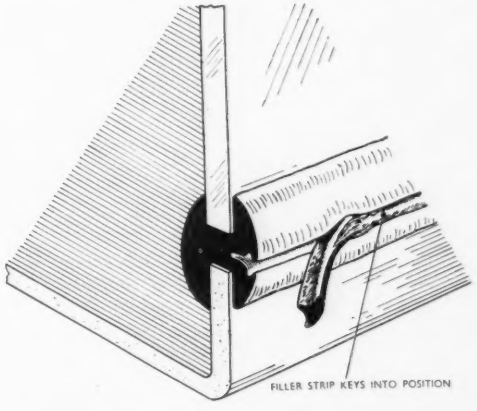
The non-return valves already mentioned, as well as keeping contamination in, when placed in the ejector system, guard against a pressure rise in the box.

Precautions must also be taken where a relatively large vacuum chamber exists in a box. A sudden leak here could lead to an implosion of the box; therefore a pressure relief device must be fitted, such as a mercury lute.

Handling

For general handling the operator will be working in rubber gloves, the gauntlets of which are secured to the face of the box, as seen in Fig. 3. As they may perish or become torn, a means must be found to change them without causing a leak, and the best arrangement at present is the use of the glove with the beaded opening, which fits on a flange having two grooves in either of which the bead can lie. A damaged glove is moved to the outer groove while the new glove is slipped on to the inner. The old glove is then drawn into the box. With the depression inside the box, any leak will be inwards and activity carried

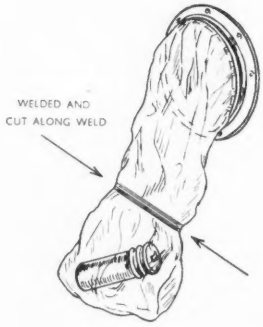




away from the opening, but with the new glove securely clamped there is little chance of any leakage and the area between the two grooves can be monitored and washed clean if necessary. Gloves may be right and left hand or ambidextrous and are 24 in. long, the human reach having an important bearing on the design of both boxes and the equipment used. Mainly in latex rubber, they can be obtained in Neoprene or p.v.c. In p.v.c. the hand is produced in the usual manner by dipping. but the cuff, of thinner sheet, is welded on. A few experimental full-length gloves have been produced. As the hands are much thicker they are only of use where sensitivity of fingers is not needed

or where p.v.c. is essential because of its properties. In this country, Neoprene gloves have not been found as long-lived as experience with this material in other spheres would lead one to believe.

Fig. 7.—Transfer technique.



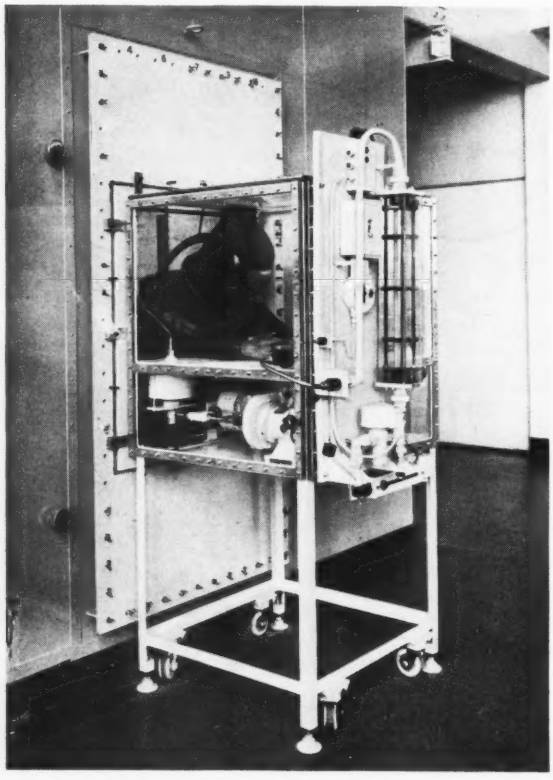
Transfer

Beside glove openings, the only other free opening into the box is the transfer port. During operation all traffic must pass through this opening (whether in or out) including specimens, tools, equipment, trash and everything needed in the box whatever.

Little need be said of the air-lock type of transfer arrangement; shown on box in Fig. 2, it is well known in principle and the drawbacks for highly toxic work are obvious. It is quicker than the system next described, which is an obvious advantage where its weakness of sealing is permissible. For inert atmospheres, it may need pumping down between each transfer to prevent dilution. The transfer bag system makes use of ability to weld p.v.c. allied to the principle of the glove change. This is shown in Fig. 7 which is self-explanatory.

The elegance of such a system can be readily appreciated. At no time is any portion of the box open to the laboratory.

Fig. 8.—Servicing a glove box from a decontamination area.



The material when separated from the parent bag is itself safely sealed in its own packet, and, if the box atmosphere is inert, the contents also will be in an inert atmosphere. If the contents of the transfer need further work on them in another box the packet can easily be cut open after transferring.

Decontamination

It will be obvious that decontamination is an important aspect of active handling and this has a great bearing on finishes. The outside must have high mechanical bond and a good hard gloss finish that is easy to clean from general

Appareillage de Manutention à distance pour les travaux en alpha

Les particules alpha n'ont qu'une puissance de pénétration relativement réduite, et la considération la plus importante lors du maniement des matières alpha-actives est d'empêcher les particules contaminées d'atteindre l'intérieur du corps. La retenue ne nécessite pas de protection intensive et le maniement s'effectue normalement dans des boîtes gants, dans lesquelles la pression est maintenue inférieure à une atmosphère de sorte que toute fuite est vers l'intérieur et non pas vers l'extérieur.

Les matériaux appropriés pour la construction des boîtes comprennent le bois, l'aluminium, la fibre de verre imprégnée de résine, les matières plastiques acryliques telles que le "Perspex," ou des groupes d'éléments à cadre en acier. L'aération pourra être par ventilateur ou éjecteur. Là où des atmosphères inertes sont requises, la recirculation et la purification pourraient présenter des avantages particulièrement avec les gaz chers tels que l'argon. Les gants pourront être en chlorure de polyvinyle, bien que le caoutchouc latex s'emploie plus souvent. La décontamination est un aspect important de la conception; et elle pourrait avoir un effet considérable sur le type de fini prévu. Les types de boîtes pourront varier des genres reposant librement à des structures reliées entre elles tout à fait compliquées.

Fernbedienungsgeräte für Arbeiten mit Alphastrahlen

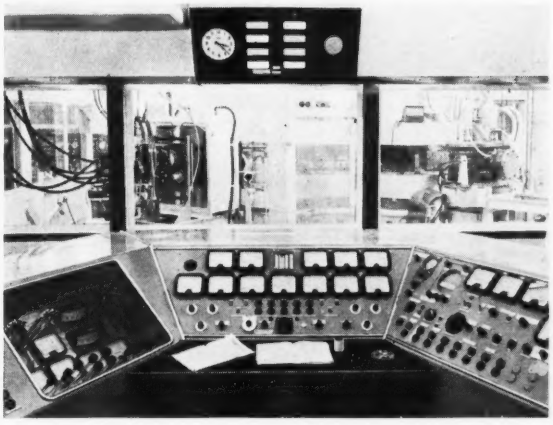
Alphateilchen haben ein verhältnismässig geringes Durchdringungsvermögen, und die wichtigste Vorbedingung für das Arbeiten mit Alphastrahlen ist zu verhindern, dass vergiftete Teilchen in den Körper gelangen. Bei Unterbringung in Behältern ist schwere Abschirmung nicht erforderlich, und die Handhabung erfolgt meist in Handschuhkästen, in denen ein Unterdruck herrscht, damit ev. vorkommende Undichtigkeiten sich nach innen und nicht nach aussen auswirken.

Zu den für Herstellung der Kästen geeigneten Materialien gehören Holz, Aluminium, kunstharzimprägnierte Glasfasern, Akrylharzkunststoffe, wie "Perspex," oder Kästen mit Stahlrahmen. Die Lüftung kann durch Ventilator oder Saugstrahlpumpe erfolgen. Wenn eine Edelgasatmosphäre erforderlich ist, kann ein Kreislauf- und Reinigungsprozess vorteilhaft sein, besonders wenn teure Gase wie Argon Verwendung finden sollen. Die Handschuhe können aus Polyvinylchlorid bestehen, allerdings sind aus Latex gefertigte Gummihandschuhe gebräuchlicher. Entgiftung ist ein wichtiger, bei der Konstruktion zu beachtender Faktor und kann für die Art der äusseren Ausführung massgebend sein. Man findet neben ganz einfachen, freistehenden Kästen auch elaborate, untereinander verbundene Konstruktionen.

Equipo de Manipulacion de Trabajo con alfa

Los partículas de alfa tienen solamente una fuerza penetrante comparativamente pequeña, y la consideración más importante en la manipulación de material alfaactivo es la de evitar que las partículas contaminadas lleguen dentro del cuerpo. El "contenimiento" no envuelve blindaje protector pesado y la manipulación se hace generalmente en "cajas de guantes," en que la presión se mantiene debajo de la presión atmosférica, de modo que cualquier fuga resulta para adentro y no para afuera.

Los materiales adecuados para la construcción de estas cajas incluyen madera, aluminio, fibra de vidrio impregnada con resina, plásticos acrílicos, tales como el "Perspex," o unidades con bastidores de acero. La ventilación puede ser por ventilador o eyector. En donde se necesitan atmósferas inertes, la recirculación y la purificación pueden tener sus ventajas, particularmente cuando se trata de gases costosos, como el argón. Los guantes pueden ser de cloruro polivinílico, aunque los más usuales son de caucho latex. La decontaminación es un importante aspecto del diseño, y puede ejercer un efecto considerable sobre el tipo de acabado provisto. Las cajas pueden variar desde los tipos reposando libremente hasta estructuras interconectadas complicadas.



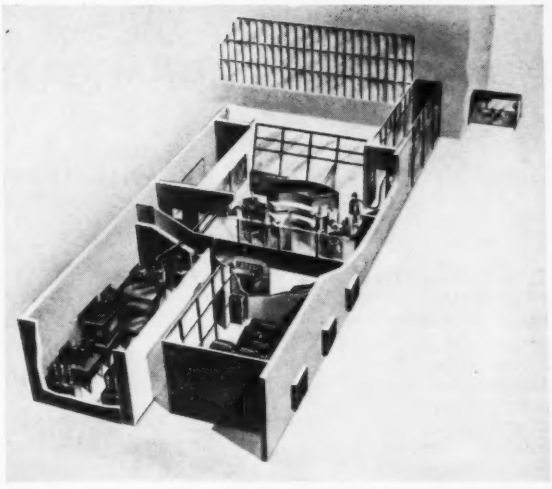


Fig. 9.—(Right) A cut-away view of the Hermes electromagnetic separator.
Fig. 9a.—(Above) Control panel of Hermes showing windows into working area.

contamination or mild active contamination. The inside may be treated with a good close hard finish covered by a coat that can be readily stripped off. During overhaul of a box this coat would be sprayed over with a further coat and the two stripped off together, carrying most of the contamination between them.

This, of course, requires the box to be taken into a special area, which is, in fact, often done, but this means that as the panels are taken off the general atmosphere becomes contaminated. Work must be carried out in special protective clothing and, when the work is finished, the outside of the box has become contaminated and needs most careful cleaning before re-entering the laboratory. Special measures must be taken, therefore, to enable cleaning of the inside of the box without taking it into the decontamination area. Fig. 8 shows the box clamped to an opening in the wall between the laboratory and the decontamination area. The inside door has been removed, as also has the box panel, and the operator in his protective suit is reaching into the box and is at work on equipment.

After the panel is replaced the box surface and the wall opening and inside door must all be carefully cleaned, the inside door then fixed and the box removed only after monitoring of the inter-space atmosphere has shown no contamination present. The laboratory side also has a door which is fixed in place when the decontamination opening is not in use.

The Designer's Approach

The designer is faced with a wide variety of requirements. As the introductory article pointed out, any operation whatever may be asked for. All the requirements of containment must be met in carrying out an experiment, indeed a large number of operations may be needed for one project; even a continuous production line of boxes. The designer will need to decide on the time factor for the operations, how many, if any, of the boxes should be interconnected—thus simplifying transfer without sacrificing size and mobility; whether the work routing is such that each box may be separate and transfer made at each stage.

If he decides to interconnect some boxes a study will need to be made of the operations and the equipment then located so that unnecessary journeys of specimens about inside the boxes are avoided. Such a set of coupled boxes is shown in Fig. 1, three double boxes interconnected.

Ancillary Equipment

Assessment must be made of the best position for ancillary equipment. A large proportion of handling boxes is required with vacuum pumps and it is necessary to decide whether to fit them in a separate chamber in the same box, or supply them in their own free-standing box. The former, with its short connection, saves pumping time, but the latter system, where it can be used, offers the possibility of replacement units quickly coupled in, whereas the former means repairs carried out through gloves while the experiment is held up. This also applies to cooling units, suction cleaning equipment and similar ancillaries.

Other Types

While the above has dealt specifically with free-standing boxes, the principles obviously apply to any alpha-handling box arrangement, of which there are a number to suit particular types of work. Some suites have been built as a row of rooms with large windows facing the laboratory, the boxes being fitted into the rooms, with their one working face brought close to the window. Two sets of gloves are used; one set on the box and the other on the room window. These were assembled in the room from a lobby at the rear by men in protective clothing who, besides installing, are able to maintain and service them.

Another similar arrangement is to provide boxes free on three sides whose backs are attached to a maintenance room.

The electromagnetic separator (Fig. 9) mentioned earlier is interesting inasmuch as the operator, clad in his protective suit, enters the chamber from the decontamination area to which it is attached, and all setting-up is carried out in this way, no other handling or transferring being done, except through the decontamination area. For such an operation, which constitutes a period devoted to setting up and preparing the machine, followed by a period when the machine can be run remotely, this is most suitable. The factors determining a choice of method would be a comparison of the time and complexity in each method.

The conditions to which these kinds of boxes are suited and their particular problems are a subject in themselves.

The author is indebted to the Director of A.E.R.E., Harwell, the Deputy Chief Engineer and the Head of Remote Handling Group, for permission to publish this article which is the result of many years work by a number of Divisions covering design, manufacture and operation.

Note.—The complete proceedings of the Glove Box Symposium held at Harwell in February are to be published in book form (Butterworths, Ltd.).

WELDING RESEARCH

Official Opening of New B.W.R.A. Laboratory

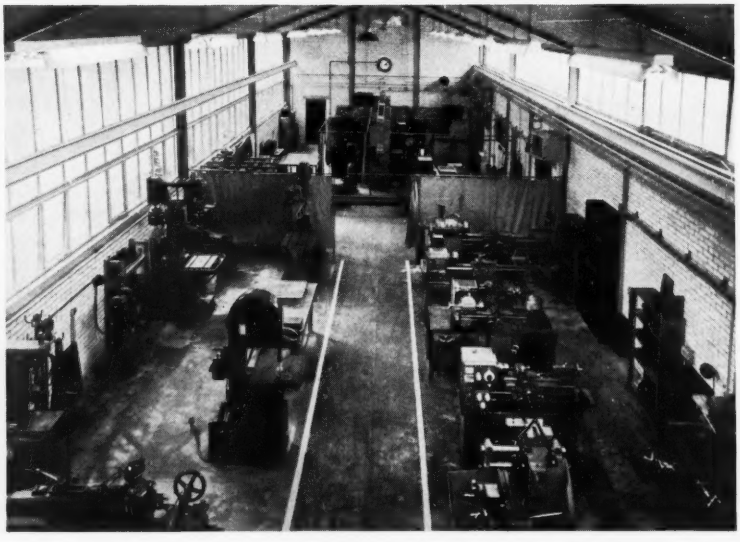
SOME idea of the wide range of work undertaken by the British Welding Research Association was afforded by the recent official opening of their new Metallurgical laboratories, at Abington Hall, near Cambridge. The opening ceremony was performed by Lord Tedder, the date chosen for the function coinciding with the Annual Luncheon of the Association. The move to the new premises commenced in the autumn of 1956.

The new laboratories have a floor area of 13,000 sq ft, and house welding laboratories, instrument room, machine shop and chemical analysis and heat treatment rooms. The building itself was designed according to the plastics theory developed by Dr. Baker of Cambridge University.

The welding laboratory proper is divided into four main bays which are so arranged that two of them can be easily viewed from an instrument room in which measurements can be made in suitable conditions, free from glare, fumes, and spatter, the welding operations being observed through windows of tinted glass.

The welding laboratory contains a comprehensive range of equipment for both metal-arc and gas-shielded welding processes. For most experimental work, automatic traversing heads are used, these giving better control of welding conditions than hand welding. Power sources include transformers, transformer-rectifier units, and motor-generator sets. A battery supply, capable of 1,000 amp discharge will be available shortly.

Work in progress in the welding laboratory at the time of the visit included the behaviour of arcs; and high-current welding of aluminium in which the ingress of air to the weld pool is controlled by the use of a special nozzle. By this means sound deposits have been achieved up to 600 amp whereas previous experience has shown 350 amp to be the limit for welds free from defects. Aluminium 1 in thick was shown being welded at 500 amp.



General view of new welding laboratory from machine-shop end.

Hot Cracking

Hot cracking investigations have been under way for some time, employing both high temperature tensile testing of weld metal and the Murex hot-crack machine, in which a fillet weld is deposited between two plates that can be rotated to apply strain, and the effect of carbon content of the weld metal for various levels of the manganese-sulphur ratio has been established. Below 0.15% carbon, a ratio of Mn/S of about 25/1 was sufficient to prevent cracking. Above 0.15% carbon, a high Mn/S ratio will not prevent cracking although it has a beneficial effect in reducing its severity.

Other work of interest in this section included controlled tungsten arc welding in which the traversing head follows an uneven contour by means of actuators responsive to the arc voltage, and the properties of welds made under carbon dioxide shielding.

Instrument Room

Equipment in the instrument room included a universal indicating and recording unit for welding time, current, and voltage; a high-speed temperature recorder for thermal cycle of heat affected zones, and oscillographic equipment.

Heat-treatment Room

There are seven furnaces of various types for high- and low-temperature heat treatment, in addition to two small melting furnaces. Furnace control is from the Instrument Room.

General Laboratory

The General laboratory provides accommodation for mechanical testing equipment and other apparatus of common interest to the various research groups. Work shown in progress included a miniature hot-cracking test technique; high-temperature brazing and high-temperature tensile testing.

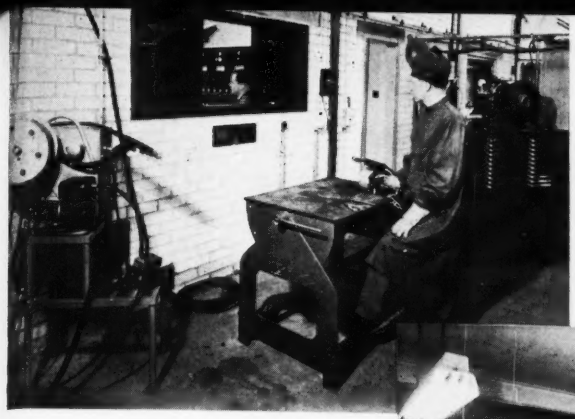
Metallography

The metallographic section comprises preparation room, microscope room, dark room, and office. The optical microscope equipment includes a $\times 2500$ Reichert metallograph and a Zetopan binocular bench microscope, both fitted for phase contrast and polarized light examination. A Vickers projection microscope and a Kentron micro-hardness tester are also provided.

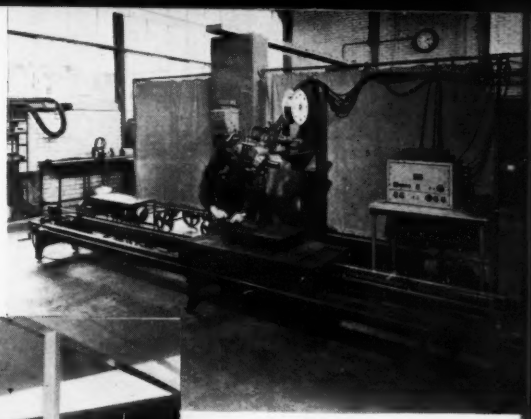
Reactive Metal Laboratory

Of particular interest to the nuclear engineer is the work being done on metals which react strongly with gases, such as titanium and, in particular, zirconium. The weldability of zirconium-base alloys has been the subject of a considerable amount of work sponsored by the A.E.A.

Welds entirely free from contamination for control purposes can be made in a chamber capable of evacuation to 10^{-5} mm Hg and filled with high-purity argon, and material for welding may be annealed or treated for hydrogen removal in a furnace capable of 1000°C at 5×10^{-5} mm Hg vacuum. Other equipment includes an autoclave for the corrosion testing of zirconium alloy welds in high-temperature water or steam.

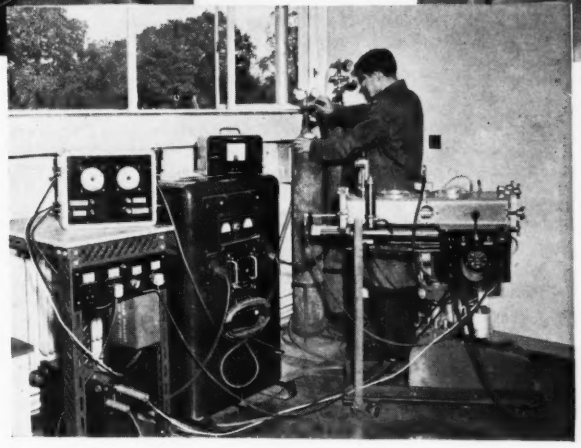


(Below) Analytical laboratory.



(Above) Manual welding bay showing observation window of instrument room, Argonaut and Sigma equipment.

(Above) Automatic traversing unit in welding laboratory, being used with a gas-shielded arc unit.



(Above) Vickers projection microscope and Reichert metallograph in the metallurgical section.

(Above) Part of the heat-treatment laboratory showing the array of furnaces.

(Left) Reactive Metals laboratory showing welding chamber and associated vacuum pump equipment and welding controls.

Analytical Laboratory

The facilities for chemical and gas analysis are now much improved. Interesting techniques shown included polarography identification of gases occurring in weld metal voids, a versatile low-pressure gas analysis apparatus and the estimation of diffusible hydrogen. The "Polarograph" is an electrolytic method of analysis in which current is passed through a cell containing the solution to be analysed, enabling analysis to be carried out on very small quantities of material.

Other Laboratories

In addition to the new laboratories, there are several smaller specialized units in various parts of the grounds. These include the Pressure Vessel and Pipe Line; Resistance Welding; Brittle Fracture; Fatigue; and Full-scale Structure laboratories. Important investigations proceeding deal with the reinforcement of openings in pressure vessels and storage tanks; the welding of gusseted pipe bends; pulsating-pressure fatigue tests in pressure vessels, and brittle fracture testing of steel plates. For this, the Brittle Fracture Laboratory is equipped with a 700-ton test rig designed to break steel plate specimens up to 48 in. long, 36 in. wide, and 1 in. thick, the load being applied by four hydraulic capsules. Recent modifications allow pulsating loads to be applied and the cooling of the specimen by frozen CO_2 or brine spray. A new test rig for 3 in. plates is under construction.

The International Institute of Welding

Report on 1957 Congress

PROGRESS made with a dictionary of welding terms in 14 languages was one of the items reported at a meeting of the British delegation to the International Institute of Welding held in London recently. Although the I.I.W. has now been in existence for nearly ten years, its aims and objects still do not appear to be as widely known as they should be. It may, then, be of interest to give a general survey of the organization, its aims and objects.

Background of the I.I.W.

The International Institute of Welding was founded in 1948 by co-operative effort between the national welding societies in Britain, a number of European countries, and in the U.S.A. Its officially-expressed objects are:—

(a) To encourage the development of welding techniques and applications and provide for the exchange of scientific and technical information relating to research and education.

(b) To assist in the formulation of international standards, for welding, in collaboration with the International Standards Organization.

(c) To organize periodical congresses.

The countries participating are as follows:—

Australia	**New Zealand**
Austria	**Norway**
Belgium	**Poland**
Canada	**Roumania**
Czechoslovakia	**South Africa**
Denmark	**Spain**
Finland	**Sweden**
France	**Switzerland**
Germany	**Turkey**
Italy	**United Kingdom**
Japan	**United States**
Netherlands	**Uruguay**
Yugoslavia	

Membership of the Institute is held not by individuals but by non-profit associations or societies primarily concerned with welding. In the United Kingdom, membership is held by the following, many of whom are founder members:—

The Institute of Welding.
The British Acetylene Association.
The British Welding Research Association.
The British Electrical and Allied Industries Research Association (E.R.A.).
The British Electrical and Allied Manufacturers' Association (B.E.A.M.A.).
The Sheet and Strip Metal Users' Technical Association.
The Aluminium Development Association.
International Institute of Welding.

The method by which the Institute carries out its objects is through a number of Commissions, each charged with the study of a well-defined subject. Each Commission is itself international and any nation may be represented if it so desires; the work of each individual commission varies from the centralization of existing information from a number of widespread sources to the initiation and carrying-out of research on an international basis. Each Commission may set up sub-commissions under its direct control and reporting directly to it.

The main Commissions, of which there are 15, are responsible for the following subjects:—

1. **Gas welding and allied processes.**
2. **Arc welding.**
3. **Resistance welding.**
4. **Documentation.**
5. **Testing, measurement and control of welds.**
6. **Terminology.**
7. **Standardization.**
8. **Hygiene and safety.**
9. **Behaviour of metals subjected to welding.**
10. **Residual stresses and stress relieving.**
11. **Pressure vessels, boilers, and pipelines.**
12. **Special arc welding processes.**
13. **Fatigue testing.**
14. **Welding instruction.**
15. **Fundamentals of design and fabrication for welding.**

While most of the above are self-explanatory, there are one or two whose titles do not clearly indicate their terms of reference. The rather vague term "documentation" for Commission 4, for example, covers the co-ordination of the work on material for the Bibliographical Bulletin of Welding published quarterly in English and French by the Institut de Sondure in Paris. In addition, it deals with the abstracting of papers and articles and the classification and translation of abstracts, and organizes exhibitions of welding journals at the international congress, to quote a few examples.

Commission 7, as another example, exists to provide liaison between the I.I.W. as a whole and the International Standards Organization (I.S.O.) as regards standardization of such items as definitions of welding positions, symbols for electrodes, and characteristics of equipment. Commission 7 acts as a kind of clearing house between the I.S.O. and all the other Commissions.

The 1957 Congress

The annual congress this year held at Essen, organized by the German welding institute D.V.S. (Deutscher Verband für Schweisstechnik), was attended by some 800 delegates and their wives. At the meetings of the Commissions, some 22 technical documents were released for publication. In the public sessions 26 papers from 10 countries were presented, the main theme of the Assembly being "The Metallurgy of Welding," and subjects included gas absorption; behaviour of welds in regard to age and caustic embrittlement; the metallurgy of brazing; the metallurgy of welding of stainless and heat-resisting steels of ferritic, semi-ferritic and austenitic types, and of titanium, magnesium, aluminium and nickel and their alloys.

The 1958 Assembly is to be held in Vienna from June 29 to July 5 and the theme for the public session is Welding in the Chemical Industry.

New School of Welding Technology

IN order to provide facilities for key men in industry to keep up to date in the latest developments in welding technique, the Institute of Welding is organizing a School of Welding Technology which will take the place of the Summer School previously held by the British Welding Research Association, at Ashorne Hill.

The new school will be held in London at the headquarters of the Institute in Princes Gate and accommodation is provided by a block booking with a nearby hotel, and the courses, each of one week's duration, have been so arranged that it will, in general, only be necessary for those attending to spend four nights away from home. Each course is limited to 40 entrants. The dates and subjects for the 1957-8 series are as follows:—

Course 1 (October 7-11). Welded design and construction of pressure vessels and pipework.

Course 2 (November 4-8). Welded design and construction in light alloys.

Course 3 (December 2-6). Welded design and construction in general and mechanical engineering.

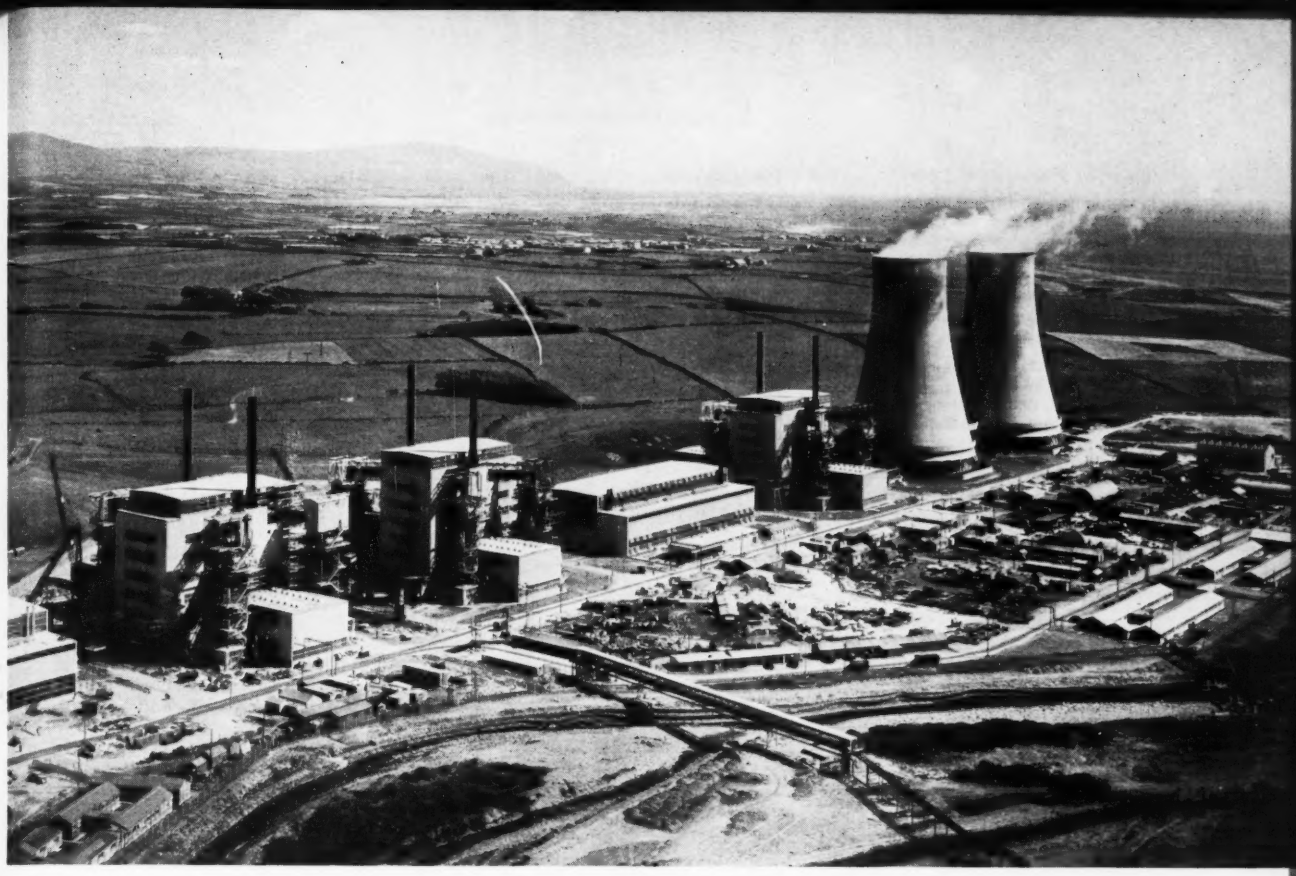
Course 4 (January 6-10). Resistance welding.

Course 5 (February 3-7). Inspection and testing of welded work.

Course 6 (March 3-7). Welded design and construction in corrosion- and heat-resisting materials.

Each course begins at 11 a.m. on the Monday and finishes at 4 p.m. on Friday, and normally consists of 10-11 lectures, of one hour, the same number of discussion periods, a number of technical films and two visits, one to a works for practical demonstrations, and one to the B.W.R.A. laboratories at Abington. The lecturers include a number of well-known authorities in the industrial, metallurgical and research fields.

The fee for each course is £12 12s. for members of the Institute and employees of industrial members and £16 16s. for others. Hotel accommodation is about 27s. 6d.-30s. per night. Further particulars can be obtained from the Institute of Welding at 54 Princes Gate, London, S.W.7.



CALDER HALL—

Contract Analysis

This article shows the diversity of engineering talent required to produce the world's first large-scale nuclear power station. Under each main heading appears a general outline of the techniques involved followed by the names of main contractors and sub-contractors with details of the plant or services supplied.

Feasibility:

Detailed design of a nuclear power station can begin when the initial feasibility study has shown that the basic system is sound and preliminary calculations indicate that the power produced will be economic. Whilst primarily a plutonium producer, Calder Hall is the prototype for the base load gas cooled graphite moderated reactor power stations which are being built for the U.K. electricity authorities. The feasibility study involved the examination of the physics of the core, heat transfer studies, metallurgical investigation on fuel, canning and constructional materials, and steam cycle analysis. This was completed in 1950.

Atomic Energy Authority.

Overall responsibility for the design and development of the complete station. Design study commenced at A.E.R.E., Harwell, in January, 1951. Detail design and construction transferred to the Production Establishment at Risley in 1953.

Babcock and Wilcox, Ltd., Babcock House, 209 Euston Road, London, N.W.1.

Feasibility study for proposed heat exchanger system. Particular attention was paid to preventing leakage of water or steam into the CO_2 circuit which is at a lower pressure.

Consett Iron Co., Ltd., Consett, Co. Durham.

Study of the metallurgical problems associated with the design of the reactor pressure vessel.

National Boiler and General Insurance Co., Ltd., National Buildings, St. Mary's Parsonage, Manchester, 3.

Consultant services to A.E.R.E. in connection with possible designs of the reactor pressure vessels. The company's consultative department specializes in questions of design, construction and inspection of all kinds of boilers and pressure plant.

Magnesium Elektron, Ltd., P.O. Box 6, Lumms Lane, Clifton Junction, Swinton, Manchester.

Design study in connection with the development of magnesium alloys suitable for carrying fuel elements.

Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester.

Manufacture of a full-scale prototype combined shut-off and control-rod operating mechanism.

Ministry of Works.

Preliminary investigation of site preparatory to placing of contracts with civil contractors. Advice on the design of the reactor pressure shell.

Parolle Electrical Plant Co., Ltd., Princes Buildings, King Street, Newcastle-upon-Tyne, 1.

Feasibility study of gas-cooled power reactor. Advisers on steam system design. Engineering of steam system and reactor gas circulators in association with A.E.A.

C. A. Parsons and Co., Ltd., Heaton Works, Newcastle-upon-Tyne.

Design study on the problem of overcoming the large relative movements of mainly thermal origin between the reactor pressure vessel and the heat exchangers. Also work on the design of the steam turbines, CO_2 ductwork, main circulators, and auxiliary CO_2 circuit.

Whessoe, Ltd., Darlington, Co. Durham.

Feasibility study of large pressure vessel to contain graphite moderator. Details of the structure developed in collaboration with A.E.A. engineers. Four major points considered by the Whessoe design team were (a) the vessels had to contain CO_2 at high pressures and temperature, (b) the design had to permit a considerable degree of expansion, (c) the graphite moderator would weigh more than 1.000 tons and require support inside the vessel and (d) a multiplicity of apertures would be required in the shells for charge-tubes and coolant ducts.

Consultants

L. G. Mouchel and Partners, Ltd., 38 Victoria Street, London, S.W.1.

Consultants for design of cooling water towers. A notable feature of the Calder towers (two for A; two for B) is the adoption of counter-flow cooling as opposed to cross-flow. For the material involved in construction the efficiency is some 40% greater for a lower cost.

Lloyd's Register of Shipping, Land Division, 4th Floor, Stone House, Bishopsgate, London, E.C.2.

Full survey and testing, both in manufacturer's works and on site, of reactor pressure vessels, heat exchangers and CO_2 ducting.

Site Selection:

Siting of Calder presented few problems. Land adjoining the existing Windscale plant fulfilled the necessary qualifications of remoteness; initial power availability and (for operational purposes) a load centre; good rock strata for foundations—each reactor weighed 33,000 tons—and an ample water supply. The new power stations must satisfy similar criteria as regards situation and, in general, sites chosen will be new. A number of authorities must therefore be consulted such as the Ministry of Town and Country Planning, local catchment boards, the reactor safety committee, insurance companies, etc. Responsibility for site selection and authorization is in the hands of the purchasing electricity authority with the A.E.A. as consultant. Provision for transport of heavily shielded containers is necessary but the stations need not be near the fuel supply centre. In time, the remoteness aspect will be of less importance and water supply should be of diminishing significance, so that siting problems will be similar to fossil-fired stations except for foundation strength.

Site Facilities:

The organization of initial services for the housing of labour forces, setting up works offices, etc., are common to all civil engineering operations. Unlike fossil-fired stations the nuclear power station requires no railway marshalling yards but reasonable road access is desirable. Because of the high precision heavy engineering work undertaken on site a number of preparation shops were set up at Calder with comprehensive facilities to simulate shop conditions as closely as possible. In order that work on the concrete shield could begin as soon as ground clearance was complete an unusual amount of heavy lifting gear was provided with exceptional lifting heights and capacities. This may or may not be a feature of future stations depending upon constructional philosophy.

Civil Engineering:

Much of the civil engineering work at Calder is conventional as, for example, the erection of turbine hall, operation rooms, offices, temporary site facilities, cooling towers, etc. The biological shield 7 ft in thickness and octagonal in shape is a different matter. Because of the large number of charge tubes penetrating the top shield and large ducts in the sides, great precision was called for in the positioning of the inserts and in the dimensioning of the main walls. In addition, a high density of concrete is required throughout, calling for special aggregate, regular batch sampling and careful compaction. Pumping was not permitted. Of particular importance is the underside of inserts because of the dangers of cavitation permitting radiation streaming. Foundations for the reactor and heat exchangers take unusually heavy loads and a high standard of workmanship throughout is therefore essential.

Taylor Woodrow Construction, Ltd., Ruislip Road, Southall.

Building and civil engineering at A and B, comprising reactor buildings, turbine halls, ancillary buildings, works and services.

Each reactor building is founded on a concrete raft, approximately 130 ft by 107 ft by 11 ft deep, heavily reinforced in both directions. The volume of concrete in each raft is approximately 5,600 cu yd and the weight of reinforcing steel (mainly $1\frac{3}{8}$ in. dia.) approximately 230 tons.

The rafts were constructed in four lifts, with each lift divided into a number of bays. Alternate bay construction was adopted throughout. Two 7-ton derricks on tracks, one each side of the excavation, were used for placing of steel and concrete.

On the foundation rafts, the octagonal biological shields were built: stringent and exacting requirements in respect of high density and uniformity of concrete had to be met.

The reinforced concrete walls, 7 ft thick, rose to heights of 90 ft above the rafts and were pierced with holes and ducts on the east and west faces. Further reinforced concrete shielding, in the form of envelope walls around the faces, was also incorporated. Suspended floors inside the envelopes provided access and working platforms at different levels.

Two concrete batching plants, fed by individual 19 R.B. grabbing cranes and a central air-flow bulk-cement-handling plant, were set up. Steam heating of aggregates (local limestone and whinstone from Northumberland) and water, together with the use of calcium chloride, permitted the carrying out of concreting operations in cold weather.

Portable petrol internal vibrators, supplemented on occasions by air vibrators, were used and the concrete was hand-compacted where specified. A wetting agent was used to avoid excess water in the mix, so as to prevent high shrinkage. The extremely close tolerances —within plus or minus 1/10 in. on both vertical and plan true dimensions—demanded in the construction of the biological shield called for the design and erection of a complete octagonal template, which required extremely accurate workmanship. A specially-designed grid facilitated the controlled discharge of concrete to the derricks.

At each corner of the reactor buildings there are heavy foundations for the heat exchangers.

A reinforced concrete roof slab 8 ft thick covers the pressure vessel shield. Bailey bridging was being used to support permanent mild steel shuttering. This roof was cast around a large number of charging and other tubes from the steel vessel.

The four 300-ft-high, 200-ft-diameter cooling tower shells were constructed in 3 ft concrete lifts. The work was carried out from an internal scaffold of prefabricated steel-angle construction.

Each turbine hall group of buildings comprises the main turbine hall, incorporating steam annexe and transformer bays, the control block and administration buildings and workshops. The main turbine hall has a structural steel framework with asbestos cement cladding and patent glazing, with a roof of patent steel decking covered with three layers of bitumen felt. Complex foundations incorporate ducted mass concrete plant bases. Four identical turbine blocks were concreted in one pour in each case. The steam and alternator ends of each block comprised 125 cu yd and 175 cu yd of reinforced concrete respectively, on surface areas of 225 sq yd and 415 sq yd respectively. One of the factors which contributed greatly to the rate of pour achieved was the use of telephone communication for the transmission of regular reports and instructions between the various working levels and the central control.

Approx. value of civil engineering contract: £5 million.

A very large number of sub-contractors supplied equipment to Taylor Woodrow (see Appendix p. 400).

Alexander Findlay and Co., Ltd., Motherwell, Scotland.

Structural steelwork for main buildings.

Reactor Vessel:

One of the main limitations which governs the reactor design is the thickness of plate which can be welded on site with the necessary quality. For thick plates special welding techniques and electrodes have been developed and 100% examination of all welds is made. Steel for the plates must meet the conditions of low creep at high temperature and resistance to brittle fracture at low temperature. Steels with improved characteristics are currently being developed. Plate preparation although relatively conventional calls for high precision and 100% ultrasonic inspection. Accurate location of the charge tubes in relation to the axis of the cylindrical vessel introduces virtually tool-room technique into site construction work. With such a large vessel, site stress relieving was deemed essential and the Calder vessel is the largest that has been treated in this way. Testing of the vessel is performed in stages taking strain gauge and lacquer readings with compressed air; the vertical load rules out hydraulic pressurization. On completion of construction, the inside of the vessel is scrupulously cleaned and coated with colloidal graphite. Subsequent thermal insulation and aluminium cladding follows conventional techniques.

Whessoe, Ltd., Darlington, Co. Durham.

Fabrication of the reactor pressure vessels. In Whessoe's shops this involved accurately cutting the 2-in. thick plate to length and width, preparation of the edges for welding on site and rolling to the correct radius. Plates for the upper and lower domes had to be hot-pressed to the required curvature, cut to exact size and the edges prepared for welding. In each case accuracy was checked by trial assembly. Only relatively small sections were prefabricated.

The remainder of the welding was carried out on site by welders who had proved their ability to weld to Lloyd's Class I standards. Sub-assemblies were lifted into position in the reactor building for final welding. A 100% X-ray examination was carried out. Finally, the complete vessel was stress relieved. Total number of vessels supplied to A and B: 8.

British Oxygen Gases, Ltd.

Argon-arc cutting and welding gear. Supplied to Whessoe.

Burnett and Lewis, Ltd.

Single adsorber Humidryer and filter for removing all traces of oil mist and water vapour from compressed air delivered to reactor system during construction pressure-proving tests.

Consett Iron Co., Ltd., Consett, Co., Durham.

Special steel plate, 2-in. thick for reactor pressure vessels. The steel produced for the purpose was essentially a low-carbon high-manganese steel, fully killed and grain refined by a special technique. It was cast into "slab" form moulds, giving ingots weighing 15-tons, each ingot being specially hot-topped in order to avoid the possibility of piping or lamination in the main body of the steel.

The chief characteristics of this steel are essentially its toughness or lack of brittleness under a wide range of temperatures, down as low as −30° C, coupled with very satisfactory welding properties which facilitate the production of welded joints free from minute cracks, and with properties very closely approaching those of the plates themselves. The steel was then known as Consett Lowtem (since renamed Conlo), and has acquired a high reputation as one of the toughest mild steels available.

The fact that grain refining was achieved by the use of a special alloy and not by aluminium alone, guaranteed much superior resistance to creep at elevated temperatures than would have been the case had aluminium alone been used for this purpose.

Costain-John Brown, Ltd.

Lifting reactor pressure shell sections into position. Sub-contract to Whessoe.

Darlington Insulation Co., Ltd., 38 Great North Road, Newcastle-upon-Tyne, 2.

Darlington 85% magnesia, metadextramite, and No. 1 armouring compound as insulating material for reactor pressure vessel, heat exchangers and station pipework. On the pressure vessel the insulation is 9-in. thick and special provision was made to support the material and allow for the necessary expansion and contraction of the metal. The insulation is covered with aluminium sheet. Supplied to Whessoe, Babcock and Wilcox and A.E.A. Darlington insulation products are manufactured by the Chemical and Insulation Co., Ltd.

English Steel Forge and Engineering Corporation, Ltd.

Forgings for reactor pressure vessel. Two forged rings, 13 ft 8 in. dia., weighing 12 tons and 260 inlet and outlet branches, weighing 42 tons. Supplied to Whessoe. Value: £32,000.

Hancock and Co. (Engineers), Ltd., Progress Way, Croydon.

Oxygen-acetylene cutting machine specially designed for cutting charge tube apertures in the upper dome of the reactor pressure vessel.

Honeywell-Brown, Ltd., 1 Wadsworth Road, Perivale, Middlesex.

Electronik multiple-record strip-chart recorder. Used for recording temperature of reactor vessel during stress-relieving.

Murex Welding Processes, Ltd., Hertford Road, Waltham Cross, Herts.

Murex Vodex welding electrodes, exclusively used for welding reactor pressure vessels.

Pantak, Ltd., 72-76 Alpha Street, Slough, Bucks.

Equipment for X-ray inspection of welds on pressure vessel. The Pantak MC 300 mobile unit is rated 300 kV at 15 mA. It comprises a control unit, H.T. generators and cables, X-ray tube, shield and associated oil cooling system, mounted on a four-wheeled truck.

Ultrasonoscope Co. (London), Ltd., Sudbourne Road, Brixton Hill, London, S.W.2.

Ultrasonoscope flaw detection equipment for examination of steel plate. Supplied to Whessoe.

Unit Superheater and Pipe Co., Ltd., Unit Works, Swansea.

A and B: 448 charge stand-pipes, 16 irradiation stand-pipes, 6 viewing tubes, 32 burst slug detection tubes and 32 thermocouple tubes, involving over 14,000 ft of metal arc welding to Lloyd's Class I standard. This involved taking 6920 X-ray films.

The manufacture of the charge tubes required working to very close tolerances with special regard to straightness. The welding had to be of the same high standard as the pressure vessel to exclude any possibility of gas leakage through defective welding. All the welds were radiographed, using radioactive Iridium 192, 2 by 2 mm sources and Kodak Crystallex X-ray film. Lloyd's Register of Shipping carried out 100% inspection.

Graphite:

From a material quality point of view graphite is the most critical component of the plant. Contamination must be reduced to an exceptionally low value and final block density must be high. Machining of the raw blocks is a mass production precision operation which must be carried out under clean conditions. Absence of contamination during handling is of equal importance to quality of raw material. In addition, dust can be a health hazard to machine operators. Similarly, during the placing of the graphite—calling for great precision and care—the atmosphere must be controlled and operators subjected to a rigorous routine to ensure no carry-over of dust into the reactor. Entry into the reactor is only possible through the main ducts. The stringent conditions apply equally to the installation of the rolling bearer members, the charge pans on top of the pile and the tie bands holding the structure in place.

Acheson Colloids, Ltd., 18 Pall Mall, London, S.W.1.

"Dag" dispersions of colloidal graphite to protect inner surface of reactor pressure vessel.

British Acheson Electrodes, Ltd., Grange Mill Lane, Wincobank, Sheffield.

Over 1,000 tons of machined graphite was supplied for each reactor. The major part of the order was manufactured at Sheffield. An exceptionally high standard of graphite was required because of the adverse effects of impurities.

Matthew Hall and Co., Ltd., Matthew Hall House, Dorset Square, London, N.W.1.

Responsible for installation of thermal shielding graphite support features, laying graphite blocks, fabrication and installation of some burst slug detection gear, charge-tube cooling assemblies, ventilation, plant erection, provision of pipelines and other mechanical services.

Newburgh Engineering Co. Ltd., Bradwell, Sheffield.

Meehanite castings for charge pans. One pan serves 16 fuel channels. Fuel element support struts.

Pollard Bearings Ltd., Ferrybridge, Knottingley, Yorks.

Graphite support bearings.

Reactor Building

A.E.I. Lamp and Lighting Co., Ltd., 18 Bedford Square, London, W.C.1.

Battened channels carrying 5 ft Mazda fluorescent lamps mounted above a Perspex ceiling in reactor and turbine control rooms.

N. G. Bailey and Co., Ltd., Burley Vale Works, Weaver Street, Kirkstall Road, Leeds, 4.

Installation of internal wiring for lighting, heating and small power services in all buildings; installation of thermocouples and compensating cables and a large amount of the control and instrumentation cabling work in the reactor buildings and turbine hall. Main contract to U.K.A.E.A.

Chloride Batteries, Exide Works, Clifton Junction, Swinton, Manchester.

Two standby batteries. Each consists of 120 OFW.13 Chloride Plante cells with a capacity of 1,950 Ah at the 10-hour rate of discharge assembled in lead-lined wood boxes. The batteries are each connected in parallel with a twin-bulb 400 kW mercury-arc rectifier set at 270 volts. Under normal conditions this provides a floating trickle charge across the 120 cells—2.25 volts per cell. Each battery is capable of supplying 1,200 amperes for half an hour.

Crossley Bros., Ltd., Openshaw, Manchester, 11.

Four auxiliary Diesel generating sets, one per reactor building. Each Brush alternator is rated at 500 kW. The prime mover is a Crossley 6 HSN, rated 800 bhp at 600 r.p.m.

English Electric Co. Ltd.

Auxiliary switchgear for reactor building.

Two 11,000-V metal-clad switchboards for use with reactors Nos. 1 and 2, each comprising 13 units of the OLD1B and OLE1B types.

Two 13-panel control and relay boards for the remote control of the above switchboards, located in the main operating room.

Two 13-panel 415-V auxiliary airbreak switchboards, type OB3, for the reactor buildings.

Two 15-kVA motor-alternator sets and their control gear, associated with the station battery.

English Steel Forge and Engineering Corporation Ltd., River Don Works, Sheffield.

Supply of 1,800 tons of heavy rolled steel plate for reactor thermal shield. 180 tons of graphite support plates. Value: £90,000.

Evans Lifts Ltd., Abbey Lane, Leicester.

Four heavy-duty electric goods/passenger lifts—one for each reactor building.

Felco Hoists Ltd., 29 Cromwell Road, South Kensington, London, S.W.7.

Various quantities of Felco standard and super roller-bearing chain blocks. Felco short headroom electric wire rope pulley blocks and other Felco lifting appliances.

Film Cooling Towers (1925) Ltd., Lionel Road, Kew Bridge, Brentford, Middlesex.

Eight all-film-flow induced draught steel shell cooling towers, each 7 ft 6 in. square by 14 ft high. Each tower is designed to cool 9,000 gallons of water per hour from 92.25°F to 80°F., when working at a wet bulb temperature of 60°F.

The towers are fitted with Airscrew axial flow 48-in. diameter fans. The fan motors are designed for operation on direct current supply, with a varying E.M.F. from 275 to 330 volts. At design conditions, the fan passes 21,375 cfm through the tower, dissipating 1,100,000 BTU per hour. The fans discharge horizontally from the side of the cooling towers. Main contract.

James Howden and Co. Ltd., 195 Scotland Street, Glasgow, C.5.

Eight induced draught fans designed to deliver 33,300 cfm against 13.3 in wg (A). Each fan is driven by vee-rope from a 120 bhp motor. Used for air-cooling reactor pressure vessel.

Lancashire Dynamo Group.

Eight motors rated 120 bhp for driving reactor shield cooling fans. Two per reactor building, supplied to James Howden for A. Similar order for B.

Laurence Scott and Electromotors, Ltd., Norwich.

Twelve 50 to 70 bhp electric motors for biological shield cooling fans. Eight sets of high-speed change-over contractors for instrumentation power supply. Main contract. Approx. value: £12,000.

Stringer and Son (CN) Ltd., Crown Engineering Works, Cradley Heath, Staffs.

One 25-ton electric hoisting crab with E.M.B. Microsen equipment to give creeping speeds on lift or lower. Cost: £3,000.

Tudor Accumulator Co. Ltd., 137 Victoria Street, London, S.W.1.

One 240-V station battery complete with charge and control equipment and distribution boards for A: similar for B. Supplied to A. Reyrolle. Total cost: £21,500.

Four 50-V switch tripping and control batteries complete with charge and control equipment and distribution boards for A: similar for B. Supplied to English Electric. Total cost: £5,000.

Windley Bros. Ltd., Crown Works, London Road, Chelmsford, Essex.

Crown surface tables and straight edges. These tables—hand scraped flat to 0.00015 in. from a mean true plane over the whole face—are used for examining fuel elements.

Fuel Elements:

Uranium ore is now mined commercially in many parts of the world. Initial treatment follows familiar practice to arrive at an ore concentrate which is shipped to the U.K. for final refining and preparation of the metal. Organic solvent extraction techniques have been developed which are followed by magnesium reduction. The fuel cans—which must be compatible with the uranium and of low thermal neutron cross section—called for the development of a range of magnesium alloys. Heat transfer demands led to a transverse, extended-surface shape. As with the graphite, absolute cleanliness and freedom from contamination is essential at all stages in the production of fuel elements. Cans for Calder were machined from solid billets, a single start helical fin being formed. New shapes will probably allow extrusion techniques to be employed. Handling of fuel elements after irradiation calls for special shielded transport. Subsequent plutonium extraction and uranium recovery is not dissimilar to concentrate refinement except that all initial stages must be shielded and operated by remote control, and criticality conditions prevented.

U.K.A.E.A.

Development, design, testing and production of fuel elements at Springfield works, industrial group. After irradiation elements are transferred to Windscale for plutonium extraction.

Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middx.

Machining of fuel element cans.

Birmetals, Ltd., Woodgate Works, Quinton, Birmingham, 32.

Magnesium alloy Magnox bar for fuel cans. Melted, alloyed and cast by semi-continuous method into billets for direct extrusion into bar; section suitable for machining to required design.

Charge and Discharge:

The charge and discharge equipment at Calder Hall has been designed to operate when the reactor is shut down. Future reactors will be provided with equipment able to operate not only under pressure but also under load. At Calder the functions of charge and discharge were separated into two sections. In both, however, handling of the fuel elements both for picking up and placing in position is automatic and sensitive feel gauges were developed to eliminate the risk of damage to the element or dropping them down the reactor channels. The discharge machine is heavily shielded and the magazine which holds the elements is cooled to prevent melting the elements before transfer to the storage pond. Ancillary equipment to the machines includes the locating head and charge chute which comprises a rotating pivoted, tubular arm that can register with any one of 16 channels. Special cables were developed for carrying the elements and for transmitting signals from the instruments; the cable grabs are interesting examples of precision work.

Strachan and Henshaw Ltd., St. Philips, Bristol 2.

Complete fuel-handling equipment for the two reactors at A, comprises eight charge machines, eight discharge machines, overhead travelling cranes, traversers, well hoists, coffin cars and ancillary equipment.

Barr and Stroud Ltd., Caxton Street, Anniesland, Glasgow, W.3.

Remote viewing facilities for operator controlling the placing of discharged fuel elements in the coffin.

Brookhirst Switchgear Ltd.

Multi-motor, SC reversing and SC control equipment for charge and discharge motor drives and associated equipment. Supplied to Strachan and Henshaw Ltd.

British Insulated Callender's Cables Ltd.

P.T.F.E. insulating cables (two kinds) for actuating reactor grabs. Supplied to Strachan and Henshaw Ltd.

British Thomson-Houston Co. Ltd., Rugby.

Electric motors for driving fuel element charge and discharge machines.

David Brown Companies, Meltham, Huddersfield, Yorks.

Worm gear reduction units included in drives of fuel handling equipment.

J. S. Forster and Co. Ltd., Powis Avenue, Tipton, Staffs.

Crane girders for overhead electric travelling crane serving reactor charge floor. Supplied to Strachan and Henshaw.

Lancashire Dynamo Group.

Ward Leonard set for reactor overhead electric travelling crane. Six motors in line: 30 bhp, 5 bhp and mg set. Supplied to Strachan and Henshaw; one set per reactor building at A and B.

Royce Electric Furnaces Ltd., Sir Richard's Bridge, Walton-on-Thames, Surrey.

Low-temperature forced-air-flow cabinets for drying fuel-element baskets after the elements have been discharged.

Tangyes, Ltd., Cornwall Works, Smethwick, Birmingham.

A total of 44 Tangye hydraulic cylinder and rams, of various capacities up to 35 tons, are incorporated in the fuel charge and discharge equipment. Supplied to Strachan and Henshaw. Approx. value: £12,000.

Widnes Foundry and Engineering Co. Ltd., Widnes, Lancs.

Five special cast iron vessels for conveying discharged fuel elements from reactor building to cooling pond. Each vessel measures 5 ft. 8 in. o.d., 6 ft. 3 in. high and weighs about 28 tons.

Wharton Crane and Hoist Co. Ltd.

Each blower house contains one 15-ton, three-motor overhead electric travelling crane of 56 ft 4 in. span. At full load they have a hoisting speed of 15 fpm, but each crane incorporates the Wharton "Slomax" creep-speed system to provide alternative hoisting speeds of 3 fpm.

Burst Slug Detection

Each of the fuel channels is provided with a bleed tube which transfers coolant gas through the reactor wall to a valve system, filter and cooler system to precipitation chambers and scintillation counters. All the sensing tubes are of stainless steel as are the associated units. Many miles of tube (which must, of course, be scrupulously clean) are employed and the 54 way valves have been specially developed to be automatically rotated, ganged with the counting equipment. The whole system must be able to operate at high pressure without leakage. Conventional recording is employed but data-handling equipment is likely to be used in future stations. This gear for the detection of faulty fuel elements is the largest single instrument in a reactor and involves the interconnection of a wide variety of disciplines.

Plessey Nucleonics, Ltd., Weedon Road, Northampton.

Burst-slug detection gear comprising 11 precipitators per reactor: eight for the fuel channels, one for bulk sampling and two spares. Also a number of shut-down amplifiers. The precipitator pressure vessels each weigh 25 cwt: they are cast and machined.

Accles and Pollock, Ltd., Oldbury, Birmingham.

Main contractor to A.E.A. for straight tubing in stainless steel and mild steel. Several hundred miles of small bore stainless steel tubing for burst slug detection. Low surface contamination of metals such as copper, lead and zinc. For control rod sheaths a specially low cobalt content of .01% in stainless steel.

Delapena and Son, Ltd., Zona Works, Cheltenham, Glos.

Delapena induction heating generator rated at 20kW; operating frequency, 500 kc/s. The equipment was used for brazing joints in burst slug detection pipes of stainless steel, inside the reactor. The joints consisted of a 2½-in. long stainless steel sleeve covering the joint formed by butting together two lengths of ½-in. diameter stainless steel tube. The brazing material employed was pure copper and no flux was used.

The Delapena equipment was designed so that the heater could be placed inside the reactor: a changeover switch was incorporated so that either of the work coils could be energized.

Richard Klinger, Ltd., Klingerit Works, Sidcup, Kent.

Supply of 440 cock manifolds for burst slug detection gear. The sampling pipes are welded into the manifold cock bodies. The cocks are of three-way construction and are ganged together to form an eight-unit manifold in two groups of four. Each cock is sealed by a renewable sleeve of asbestos, which is compressed around a parallel plug with a lapped finish. Stainless steel eyelets in the sleeve protect the packing from the action of the passing fluid. The position of the eyelets is fixed by a moulded ridge on the outside of the packing sleeve which fits into a corresponding groove in the manifold body.

Supplied to A.E.A. Approx. cost: £18,000.

Marston Excelsior, Ltd., Fordhouses, Wolverhampton.

CO_2 heat exchangers and stainless steel tube bundles for burst slug detection gear.

Pye, Ltd., Cambridge.

Closed circuit TV for inspecting fuel channels. The equipment comprises a camera, type 2035 or alternatively a smaller unit, 2044, lowered into the channel by a hose with provision for CO_2 cooling. The control unit and picture monitors are mounted on a four-wheeled trolley.

Reavell and Co., Ltd., Ranelagh Works, Ipswich.

Four special SA.6E carbon-ring compressors (two working, two standby), each with a capacity of 1,960 lb per hour of CO_2, the suction pressure being 97 p.s.i.a. and the delivery pressure 120 p.s.i.a. The machines run at 375 r.p.m. taking 10 b.h.p., and are driven through Vee-belts from Laurence, Scott 20 h.p., 970 r.p.m. totally-enclosed, fan-cooled Trislot squirrel-cage motors.

These machines compress the CO_2 passing from the burst cartridge detection equipment, in order to inject it from the closed cycle into the main circuit.

These machines are of the crosshead type, the piston and piston rod packing being of carbon so as to enable the machine to work without any cylinder lubrication at all, and avoid completely oil contamination of the gas. Two sets of glands are fitted to the piston rod, and the space between them is connected to a small bleed receiver with a pressure switch which, when the pressure in the bleed receiver rises to a pre-determined level, starts up a special SA.4 carbon ring CO_2 compressor, there being one of these auxiliary compressors to each pair of main compressors.

The auxiliary compressors run at 375 r.p.m. and the suction pressure varies between 25 and 17 p.s.i.a., and they also deliver against the same pressure as the main compressors, namely 120 p.s.i.a. Each auxiliary compressor has a capacity of 50 lbs. of CO_2 and takes 4½ h.p. They are driven by Laurence, Scott 10 h.p. 965 r.p.m. motors of the same type as the main compressors.

The receivers for both the main and the auxiliary compressors were manufactured by the Empyrium Welding and Manufacturing Co., and the pressure switches for the auxiliary compressors were manufactured by the Budenberg Gauge Co. Motor starters are of the SC latch-in type by Brookhirst.

Talbot Stead Tube Co. Ltd., Green Lane, Walsall.

Stainless steel tubes.

Control Rods:

The safety of the reactor depends upon the proper working of the control rods and the associated electrical circuits. Although the neutron absorbing rods themselves are simple pieces of equipment the drive mechanisms have to operate in an atmosphere of dry carbon dioxide which introduces special lubricating problems. The mechanisms themselves are precision engineering work and reliability is the prime design consideration. The rods must be positively held at all pre-set positions and must be capable of withdrawal or re-entry at variable speeds with additional provision for emergency rapid injection and appropriate deceleration at the end of the travel. The external electrical circuits associated with the control rods are substantially conventional except that a fail-safe philosophy must be adopted throughout the design.

Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester.

Combined control and shut-off rod-operating mechanisms. Sixty units for each reactor. The system provides for coarse and fine control. Each mechanism employs a synchronous motor of the variable-reluctance type.

Hadfields Ltd., East Hecla Works, Sheffield.

Special boron-steel for control rods.

Rocol Ltd., Rocol House, Swillington, Leeds.

Lubrication of reactor control rod mechanisms by Molytox, Molypol and Molysil Var. Molytox is a suspension of molybdenum disulphide in alcohol together with a binding resin, employed to give a dry lubricating film and to prevent rust. With Molypol larger particles are suspended in water, whilst Molysil Var is a suspension in solvents with a silicone binding resin.

Heat Exchangers:

Unlike conventional fossil-fired stations a dual pressure steam cycle is employed at Calder. Although the individual pressure circuits are not unlike conventional boiler house technique with relatively low loading in terms of pressure and temperature, heat transfer from the coolant gas to the steam circuit presents special problems. High heat transfer characteristics must be allied to a low total pressure drop through the circuit. This has led to the development of studded tubes which in some future stations will be replaced by rolled extended fin surfaces. A high quality of manufacturing workmanship is essential and batch testing for hermetic sealing is necessary. To eliminate the possibility of steam leakage into the coolant circuit, all connections are external to the main heat exchanger shell. Special sleeves minimize thermal stress. The large dimensions of the shell call for heavy precision engineering of a high order, and due to transport difficulties only partial shop assembly is possible.

Babcock and Wilcox, Ltd.

Four heat exchangers per reactor giving a total of 32 units at A and B. Dual-pressure cycle, shell and tube construction with elliptical section studs welded to tubes to provide an extended heat transfer surface. Plates for pressure shell rolled to shape or, for the end domes, hot-pressed on a Fielding and Platt 2,000-ton press. Sections of the shells were prefabricated and stress-relieved in the shop preparatory to transport to site. On site welding was to Lloyd's Class I standard, a full radiographic examination being made. Each heat exchanger is 80 ft. high by 18 ft. diameter.

F. W. Berk and Co., Ltd., Shore Division, Brent Crescent, North Circular Road, London, N.W.10.

Shotblasting of heater coils to BSS. 2569 Pt. 1.

Bivac Air Co., Ltd., Beehive Works, Marsland Street, Portwood, Stockport.

Bivac C portable industrial vacuum cleaner incorporating patent Clear-Flo filter restraining dust down to one or two microns in size.

Keith Blackman Ltd., Mill Mead Road, London, N.17.

Steam cyclones.

J. Brockhouse and Co. Ltd., Victoria Works, West Bromwich, Staffs.

Roller bogies for heat exchangers.

Cambridge Instrument Co., Ltd., 13 Grosvenor Place, London, S.W.1.

Dissolved oxygen recording outfit for analysing water circulating through the heat exchanger.

Chesterfield Tube Co., Ltd., Chesterfield.

Hot-drawn seamless-steel tubes 10¼ in. o.d. in lengths exceeding 15 ft for economizer and superheater boxes for stud tube boilers. Manufactured from steel having an ultimate tensile strength of 28/32 tons per sq. in. Large quantities of extruded stainless steel hollows supplied for cold drawing by tube-making associates. Manufactured from 18/11/1 chromium, nickel, titanium steel. Finished tubes used in heat exchangers.

Colvilles, Ltd., 195 West George Street, Glasgow, C.2.

Coltuf 28 steel for construction of heat exchanger shells.

Costain-John Brown, Ltd., 73 South Audley Street, London, W.1.

Lifting heat exchangers into position on concrete block foundations using gin poles and special anchorage blocks designed by C.-J.B. and made by Taylor Woodrow.

Dewrance and Co., Ltd., Great Dover Street, London, S.E.1.

Supply of heat exchanger mountings and parallel slide valves for the steam and feed lines. The mountings include Dewrance-Consolidated safety valves of the Maxiflow type; each valve-head being of the Thermodisc type, designed to prevent distortion of the actual seating face and subsequent leakage. The bronze water gauges are sleeve packed and fitted with bi-colour illuminators, which provide accurate and instantaneous readings of the boiler water level.

Edwin Danks and Co. (Oldbury), Ltd.

Extensive system of galleries and ladders for heat exchangers.

Electric Furnace Co., Ltd., Netherby, 161 Queens Road, Weybridge, Surrey.

Equipment for stress-relieving heat-exchanger vessels. The circumferential welds on the vessels were stress relieved by wrapping inductor cables carrying high frequency current at 2,200 c/s around the vessel on either side of the weld. Eight cables were used, four on either side, the total power taken being 200 kW.

The high frequency current was distributed by copper busbars to a number of junction boxes sited under the various welds in the vessel. Asbestos lagging was used over or under the cables, held in place by non-magnetic clamps.

The system also enables the plates on either side of the weld to be pre-heated and, if necessary, the heating continued during the welding operation. A different method of cable clamping is then used. Approximate cost: £20,000.

Hayward Tyler and Co., Ltd., P.O. Box 2, Luton.

A total of 64 glandless circulating pumps (32 for A, 32 for B). These pumps circulate water in the heat exchangers. Apart from absence of leakage, these pumps have several other features. The inclusion of both pump and motor in a rigid pressure shell, mounted in a vertical position, eliminates problems of alignment. No baseplate is necessary, as the whole unit can be suspended from above or carried by supporting the suction and discharge flanges.

Both thrust and journal bearings are of the tilting-pad type employing respectively a disc and sleeves of plastic material running against stainless steel pads. These bearings are water lubricated and require no attention. Supplied to Babcock and Wilcox.

Mather and Platt, Ltd.

H.P. and L.P. standby circulating pumps.

Lancashire Dynamo Group, St. Stephen's House, Victoria Embankment, London, S.W.1.

Sixteen circulating pump motors rated at 18 h.p. and 45 h.p. for heat exchangers. Located in pump house at foot of each heat exchanger. Supplied to Babcock and Wilcox for A; repeat order for B.

Negretti and Zambra Ltd., 122 Regent Street, London, W.1.

Hygrometers.

The Pulsometer Engineering Co., Ltd., Nine Elms Iron Works, Reading.

Supply of 24 BEX 1½-in. bore centrifugal pumps for heat exchangers.

J. Rigby and Sons Ltd., Salford.

Oval rolled section for heat exchanger studs.

Royles, Ltd., Irlam, Manchester.

Strainers for steam services. Quantity, 128—ranging from 3-in. bore to 8-in. bore.

St. George (Engineers) Ltd., Ordsall Lane, Trafford Bridge, Manchester.

Shot-blast equipment for cleaning heat exchanger assemblies.

Silica Gel, Ltd., Astoria House, 62 Shaftesbury Avenue, London, W.1.

Five silica gel air-drying units used to remove moisture during the construction of the stud boilers.

Sturtevant Engineering Co., Ltd., Southern House, Cannon Street, London, E.C.4.

Six standard No. 5 portable vacuum dust collectors for general use, including cleaning of the heat exchange stud tube elements. Supplied to Babcock and Wilcox.

Welding Supplies, Ltd., Beechings Way, Gillingham, Kent.

Over 1,000,000 ft. of O.K. Unitrode—a basic-coated low-hydrogen electrode, and O.K. Versitrode, an E.317 electrode, were supplied for hand welding the heat exchangers.

Stewarts and Lloyds, Ltd.

Over 265 miles of electric resistance weld steel tubes for the heat exchangers. These E.R.W. boiler, superheater and economizer tubes are in sizes 2 in. o.d. by 7 w.g., 2 in. o.d. by 6 w.g. and 1½ in. o.d. by 8 w.g., and in accordance with B.S. 1654-1950. Supplied to Babcock and Wilcox.

Tilghmans Ltd., Broadheath, Manchester.

Shot-blast equipment.

G. and J. Weir, Ltd., Cathcart, Glasgow.

Weir feed regulators for H.P. and L.P. drums.

Main Coolant Circuit:

An unusual feature of the gas coolant circuit is the very large ducts which are employed at a design pressure of 100 p.s.i. Increasing the circuit temperature from atmospheric to operational temperature results in considerable expansions in the pressure vessel and the ducts themselves. Each circuit therefore includes a number of expansion joints which consist essentially of large stainless steel bellows mounted in frames which, in turn, are mounted in gimbals. Future stations will probably ensure that a single coolant circuit is co-planar to limit the number of directions for which movement must be allowed. Blowers for the gas, whilst not of fundamentally different design from conventional

plant, are not available for servicing and must be constructed with this in mind. A critical feature of the blower is the shaft seal to ensure no leakage of carbon dioxide from the circuit or ingress of contamination to the circuit. Drive for the blowers at Calder was required to cater for a range of 10 to 1 in speed, and although blower speed will probably be the standard control for meeting load changes in future stations this range can be reduced. The motorized valves employed in the large duct circuits are of special construction, shaft leaks being a major problem. Throughout the plant the limited servicing possible further complicates design and imposes stringent tolerances on construction.

C. A. Parsons and Co. Ltd.

For each reactor there are two main CO_2 blower houses, each serving two heat exchangers. The blowers are of the single-stage centrifugal type with an overhung impeller. Sealing is achieved by a face labyrinth seal with concentric rings attached to discs; the small amount of leakage passes into a chamber at a slightly lower pressure. Into this is fed the leakage from an oil seal at a higher pressure: the resultant mixture is taken away and separated.

The blowers have a normal capacity of 1,964 lb/sec at 284° F and 100 psi. In an emergency a pony motor rated 10/100 hp can be brought into operation. A Ward Leonard control system enables speed changes (and consequently CO_2 flow changes) to be made by remote control.

Wm. Beardmore and Co. Ltd., Parkhead Steel Works, Glasgow.

Upper and lower halves of CO_2 blower casings of 54-in bore ducting flanges.

J. Blakeborough and Sons Ltd., Brighouse, Yorks.

Thirty-two (16 for A; 16 for B) 54-in diameter power-operated wedge gate valves for coolant system. Mounted on the hot and cold CO_2 ducts between the pressure-vessels and their associated heat exchangers. Half the valves in each case are designed for vertical mounting, and half for horizontal mounting in vertical ducts. They are of outside screw construction, with cast steel casing and gate, monel metal seat and face rings, and aluminium bronze stem and tubular rising spindle. The operating gear is of electric motor-driven type, capable of opening or closing the valve in two and a quarter minutes. Remote control and remote open-shut indication.

Factors demanding special attention in design and manufacture include the working temperature of 700° F—unusually high for valves of this size; the possible radioactivity of the fluid, necessitating extra precautions against leakage to the surrounding atmosphere; and the very limited periods of access permissible during the operation of the plant, calling for maximum ease and simplicity of maintenance. The exacting nature of the service is reflected in the testing procedure, which included radiographic examination of all pressure castings; hydrostatic tests on casing and gate; seat tests under compressed air; and operating and tightness tests under full working temperature conditions.

Supplied to A.E.A. Value: £200,000.

British Thomson-Houston Co. Ltd., Rugby.

Four sets of rectifier equipment (two for A; two for B) for supplying the DC blower motors.

Made to A.E.A. specification and supplied to the order of Whipp and Bourne Ltd.

Brookhirst Switchgear, Ltd.

SC latch in control equipment for 32 18-h.p. seal and lubricating oil pumps and 8 115-h.p. auxiliary gas circulator motors. Supplied to C. A. Parsons.

Burnett and Lewis, Ltd., Redhouse Industrial Estate, Aldridge, Staffs.

Specially-designed dual adsorber Humidryers for removing water vapour from CO_2 coolant. Eight plants supplied for A and B. The main pressure vessels, three heat exchangers and all inter-connecting pipework of the Humidryer were welded with Quasi-Arc equipment and electrodes. Each drier, including all ancillary valves, electrical apparatus, instruments and controls, is supplied as a self-contained packaged unit. Main contract. Approx. value, £28,000.

Colville, Ltd., 195 West George Street, Glasgow, C.2.

Plates for main duct work and bellows units.

Consett Iron Co., Ltd.

Plates for main and auxiliary bellows units.

The Dennystown Forge Co., Ltd., Dumbarton.

Blower shaft forgings and shaft coupling forgings.

Dorman Long and Co., Ltd., Redcar Iron and Steel Works, Redcar

Plates for main and auxiliary bellows units.

English Steel Castings Corporation, Ltd., River Don Works, Sheffield.

One pair of CO_2 blower casings, weighing 30 tons. Value: £6,750.

Thos. Firth and John Brown, Ltd.

Steel forgings for gas circulators. Fan and fan-back plates, collar forgings, 54-in. bore gas duct-work flanges, auxiliary duct-work flanges, vane steel for blower casings, bolt steels and Nitralloy steel bars.

Fluidrive Engineering Co., Ltd., Fluidrive Works, Worton Road, Isleworth, Middlesex.

Thirty-two SSS (synchro self shifting) clutches for pony motor drives (10/100 h.p.) for auxiliary CO_2 blower drive at A and B.

Head Wrightson (Teesdale), Ltd., Teesdale Iron Works, Thornaby-on-Tees, Yorks.

Supplying 2,000 tons of heavy welded platework comprising casings for expansion bellows units for CO_2 ducting. Fabricated from 1½-in. thick plate: 30% automatic welding using equipment supplied by Lincoln Electric. Auxiliary ducting of 18 in. diameter ¼ in. thick incorporating lobster-back bends with cascade vanes. All to Lloyd's Class 1. Stress-relieved and radiographed. Supplied to C. A. Parsons. Approx. value: £350,000.

Robert Jenkins and Co., Ltd., Rotherham, Yorks.

Fabrication of 54 in. bore duct work in ⅜-in. mild steel plate. Total length supplied, 1,500 ft. Weight, 300 tons.

Lancashire Dynamo Group.

Twenty-eight D.C. standby motors of 18.5 b.h.p. and 7.5 b.h.p. for gas circulator lubricating pumps. (A, only; repeat order for B.) Seven motors located in each bay off buildings housing CO_2 circulators.

F. H. Lloyd and Co., Ltd., James Bridge Steel Works, Wednesbury, Staffs.

Upper and lower halves of blower casings.

Mather and Platt, Ltd., Park Works, Manchester, 10.

Driving motors for CO_2 circulators and motor-generating sets. Rated 1,500/2,000 h.p. at 854/940 r.p.m. Ward Leonard motor generator sets, each consisting of an 11-kV., 2,500 h.p. 3-phase induction motor with a speed of 750/742 r.p.m. and a generator rated at 1,730 kW. at 540/600 V.

Shell-Mex and B.P. Ltd., Shell-Mex House, Strand, London, W.C.2.

Shell APL lubricants specially formulated for the CO_2 blowers.

Stewarts and Lloyds, Ltd., Brook House, Upper Brook Street, London, W.1.

Seamless steel tubes for ancillary pipework in CO_2 circuit.

Stillite Products, Ltd., 15 Whitehall, London, S.W.1.

Therbloc mineral wool insulating slabs, together with radiused and bevelled slabs at a density of 14/16 lb./cu. ft. and Stilag rigid pre-formed pipe insulating sections.

John Taylor Dunford, Ltd., Dean Street, Newcastle upon Tyne.

Installation of Stillite thermal insulation for circulators and duct work.

Vokes Genspring, Ltd., Henley Park, Guildford, Surrey.

Constant support hangers for main and auxiliary CO_2 ducting. Quantity: approx. 150. These units are manufactured by standard techniques of fabrication, the

load frame and main frame being arc-welded. Testing is carried out on a specially designed machine, which applies load through hydraulic cylinder, and measures load by means of a straining ring.

CO_2 Storage Facilities

The Carbon Dioxide Co., Division of the Distillers Co., Ltd., Devonshire House, Piccadilly, London, W.1.

CO_2 storage and evaporation plant. Supply of liquid CO_2. The storage installation consists of four specially insulated steel tanks, with a capacity of 22 tons of liquid CO_2. Each tank has an automatic pressure-controlled refrigerator, which cools the liquid to about 0° F. and maintains the pressure at 300 p.s.i.

The tanks are filled by bulk deliveries in the Carbon Company's standard road tankers, which carry four tons of liquid at sub-zero temperatures under pressure. The vehicles are discharged by means of an electrically-driven transfer pump powered by a generator coupled to the engine. Filling or emptying a tanker takes approximately one hour and is carried out without interrupting normal working of the plant.

For use in the coolant circuit, liquid CO_2 is vaporized in four evaporators, developed and constructed by the research and development department of the Distillers Co., Ltd., in conjunction with A.E.A. engineers. The evaporators consist of two parallel banks of steam-jacketed tubes. Each unit can vaporize more than two tons of carbon dioxide an hour. The units are coupled to a manifold, giving a total output of over eight tons an hour when the main circuit is being filled or purged. The same system supplies the smaller quantity of CO_2 gas required for normal operation. Main contract to A.E.A.

Bayham, Ltd., 12 Grosvenor Place, Westminster, London, S.W.1.

Supply of five contents gauges for measuring quantity of CO_2 in storage tanks.

Dick's Asbestos and Insulating Co., Ltd., Eagle Works, North Woolwich Road, London, E.16.

Low-temperature insulation of CO_2 storage tanks. Three layers of 3-in. thick preformed cork slab with ½ in. Keenes cement. Removable covers on Bayham gauge access doors.

Metropolitan Refrigeration, Ltd., 73 Charterhouse Street, London, E.C.1.

Supply of four ¾ h.p. York 18AR air-cooled condensing units. Fitted with automatic pressure control, these machines maintain the CO_2 at a liquid temperature of 0°F and pressure of 300 p.s.i.

John Thompson, Ltd., Ettingshall, Wolverhampton.

Fabrication of four liquid CO_2 storage tanks, each with a capacity of 5½ tons.

Auxiliary CO_2 Circuits:

On some standards it could be argued that an excessive amount of auxiliary equipment was provided at Calder for the checking of pressures, temperatures, gas purity, etc., but even in future stations comprehensive instrumentation will be necessary and a purification plant will have to be installed. As a result, large quantities of auxiliary piping are required with associated valves and instruments. These valves are, in most instances, required to operate at the gas pressure and at temperatures up to the maximum gas temperature. Leakage from these must be avoided. Experience gained at Calder has led to the development of new designs. A continuous bleed from the main stream is passed through filters, cyclones and dryers to continuously purify the coolant and to extract corrosion products. An auxiliary coolant circuit is provided for shut-down operation and emergency use.

Air Control Installations Ltd., Ruislip, Middx.

H.P. cyclones for separating graphite dust from CO_2.

Sir W. H. Bailey and Co. Ltd.

Approx. 500 1-in. forged-steel valves for auxiliary CO_2 control lines.

J. Blakeborough and Sons Ltd.

Eight 18-in.-diameter cast-steel wedge gate valves, with direct manual operation and anti-friction features, for auxiliary CO_2 circuit.

Broom and Wade, Ltd., P.O. Box No. 7, High Wycombe, Bucks.

One S1 gas booster compressor; one TN8 gas compressor and two N4 air compressors, all Vee-rope driven by electric motors.

Clarke, Chapman and Co. Ltd., Victoria Works, Gateshead 8, Co. Durham.

Forty-eight special bellows units for CO_2 ducts. Special steel fabrication to Lloyd's Class 1 requirements.

Dewrance and Co. Ltd.

Dewrance large bore parallel slide valves of standard pattern but with glands which can be repacked under fluid pressure. Special packing specified by A.E.A. Dewrance-Consolidated safety relief valves of the high-lift, high-capacity type, constructed to give protection to equipment handling gases and vapours. The single ring adjustment controls blow-down only. The blow-down adjustment is not dependent upon multiple rings and cannot affect lift and capacity by disturbing the area of the secondary annular orifice.

Steam Circuits:

The steam circuits external to the heat exchangers are largely of familiar pattern; pressures and temperatures are low by modern standards but will progressively increase over the course of years. It is desirable, however, to maintain the reactor—particularly at Calder where the main object is to produce plutonium at a constant operational load. As a result, should the transmission system break down or a fault develop in the generating system, steam must be dumped. Even in power stations where build-up of higher plutonium isotopes is of less significance, dumping facilities will be provided as an additional precaution should an emergency shut-down be necessary. At Calder, the dump condensers can cater for the full operating heat output, but in future stations the capacity is more likely to be 10% or 20%. With the relatively poor steam conditions obtaining, adequate supplies of cooling water are of prime importance. At Calder a fresh water supply is available from a nearby loch, but it was deemed desirable to circulate the water and conventional cooling towers were installed. The generating stations in the first round of the programme are situated on the coast and will use uncycled sea water cooling in the condensers. Components of the steam plant are almost entirely conventional except for dumping and the control system which makes adjustment for load changes.

Aiton and Co., Ltd., Derby

Station pipework, high- and low-pressure steam mains from the heat exchanger superheater outlets to the steam receivers, from the receivers to the turbine steam chest inlet flanges, and to the steam-dumping valve inlet flanges of carbon steel and mainly of tube 16-in. outside diameter by ⅜-in. thick, with intermediate joints butt-welded by the metal arc process. These butt welds were examined by gamma-graph. At terminal points the Aiton "Corwel" seal weld joint has been used.

From the outlet flanges of the steam-dumping valves to the dump condensers the piping is fabricated from M.S. plate. Bellows expansion joints constructed from $\frac{1}{16}$-in. thick stainless-steel plate take care of thermal expansion.

High-pressure feed piping from the discharge flanges of the feed pumps to the terminal flanges at the heat exchangers is also of carbon-steel tube and again the joints are butt welded and gamma graphed.

There is an extensive system of Aiton low-pressure condensate piping, auxiliary steam, station heating, CO_2 and high- and low-pressure piping and erected by Aiton.

Sir W. H. Bailey and Co., Ltd., Albion Works, Patricroft, Manchester.

Six 36-in. cast-iron sluice valves; six 30-in. C.I sluice valves and five 30-in. C.I tilting disc check valves for cold-water recirculating units. Supplied to Mather and Platt, Ltd.

Birmingham Battery and Metal Co., Ltd., 101 Gresham House, Old Broad Street, London, E.C.2.

One hundred and sixty tons of aluminium-brass tubes for main and dump condenser (B).

J. Blakeborough and Sons, Ltd.

Valves for L.P. services in conjunction with turbo-alternator steam circuit.

William Boby and Co., Ltd., Rickmansworth, Herts.

Boby special pressure-type deaerator for make-up and hot drains tank.

Crane Packing, Ltd., Trading Estate, Slough, Bucks.

Crane system of securing and sealing, in the tube plate, the ends of condenser tubes. Supply of packing, ferrules, C.F.Z. (polytetrafluorethylene) tensilated tape, sheet and O rings.

Ham, Baker and Co., Ltd., Langley Green, Bucks.

Control of circulating water flowing through the cooling towers is effected by penstocks in the ducts leading to the ponds. Four of these penstocks have been installed at A and a further four are being provided at B. The penstocks are 6 ft wide and 4 ft high, and are made in high-grade cast iron with non-ferrous matching faces. The frame is of heavy one-piece construction; the door is held to a watertight closure by adjustable wedges faced similarly to the frame and is lifted by a heavy-section rising spindle, which is of high-tensile manganese bronze to avoid the possibility of corrosion. The hand-operated, machine-cut bevel-reduction gear can be operated by one man, the weight of the door being carried on heavy ball thrust bearings. The gearbox is supported on a pillar, which is carried on cross-channels spanning the extended side members of the guide frame. Sludge which collects in the system can be sluiced out by means of four 12-in. disc valves, and two 12-in. flat outlet valves in the culverts and ponds. A number of smaller flat outlet valves control the warm water required for de-icing purposes.

Hick, Hargreaves and Co. Ltd., Soho Ironworks, Bolton, Lancs.

Eight sets of cold water deaerators with associated shunt storage vessels (A and B).

Each set comprises a cylindrical spray deaerating vessel and a deaerated water storage vessel of 4,000 gal capacity. Vacuum in the deaerator vessel is maintained by a three-stage Hivac plant with horizontal tubular inter and after condensers. The deaerated water is withdrawn from the vessel by two Hivac double-impeller extraction pumps, with special gland sealing arrangements, manufactured in cast steel. All joints seal welded to prevent the ingress of oxygen to the system. Approximate value: £50,000.

Hopkinsons, Ltd., Britannia Works, Huddersfield, Yorks.

Valves and associated equipment including a large number of parallel-slide valves, ranging in size from 1 in. to 28 in. bore, some of the larger sizes being equipped with Hopkinsons' electric valve controls, complete with contactor units, push button control stations, etc. Other large types of valves are 10 in. and 12 in. bore combined stop and isolating valves, 12 in. bore automatic exhaust valves and 20 in. bore relief valves of the dead-weight type. In addition, a large number of Hopkinsons' non-return valves, Uniflow slide valves and Nolos slide valve steam traps are installed for various duties. Specialized equipment includes desuperheating equipment with control cubicles containing both mechanically-operated 8-way spray control valves and electrically-operated 2-way spray control valves. Several centrifugal purifiers, for the continuous purification of turbine lubricating oil, were also supplied.

Imperial Chemical Industries, Ltd. (Metals Division), Kynoch Works, Witton, Birmingham, 6.

Supplying 108 tons of condenser tubes and 142 tons of condenser plate. Approximate value: £103,000.

The Permutit Co., Ltd., Permutit House, Gunnersbury Avenue, London, W.4.

One set per station of Permutit mixed bed Deminrolit water treatment plant for heat exchanger feed water. Deminrolit plants utilize ion exchange processes to produce high quality water of the following average analysis: Total dissolved solids <0.5 p.p.m., silica <0.05 p.p.m. and conductivity <0.5 reciprocal megohms. Main contract, A.E.A.

Newman Hender and Co. Ltd., Woodchester, Stroud, Glos.

Valves and fittings.

Stewarts and Lloyds, Ltd.

Main cooling water pipes between the turbine and dump condensers and the cooling towers. The pipes were of mild steel to B.S. 534, manufactured by the hydraulic lapweld process, the main runs being 61 in. o.d. by $\frac{1}{2}$ in. thick, the pipes inside the turbine house and pump house reducing to 55 in. o.d. by $\frac{7}{16}$ in. thick, 39 in. o.d. by $\frac{3}{8}$ in. thick and $36\frac{3}{4}$ in. o.d. by $\frac{4}{16}$ in. thick. All pipes were shop-fabricated and the intermediate joints were of the sleeve type for internal welding, this work being carried out at site by Stewarts and Lloyds, using the electric arc process. Stewarts and Lloyds also supplied steel pipes for water services, in sizes ranging from $3\frac{1}{2}$ in. to 16 in. o.d. For the mains below ground Viking Johnson couplings were used and for those above ground flanges in accordance with B.S. 10 Table E were adopted. The pipes were descaled, phosphate treated and protected internally with bitumen. The external protection for the buried sections was bitumen asbestos sheathing and the pipes above ground were coated with bituminous solution.

The Yorkshire Copper Works, Ltd., Leeds.

Sixty tons of condenser tubes for A; repeat order of 60 tons for B. Total quantity at A: 13,802 tubes each 1 in. o.d. by 18 s.w.g. by 18 ft. $3\frac{3}{16}$ in. long. These tubes are in Yorkshire 70/29/1 Admiralty-mixture brass. In addition to the repeat order for B, Yorkshire supplied a further 3,428 70/30 brass tubes each 1 in. o.d. by 18 s.w.g. by 7 ft. $8\frac{1}{2}$ in. long for the dump condensers. Tubes were also supplied for the turbine oil coolers.

Turbo Generators:

Low steam conditions have resulted in the use of turbines which are in many ways old-fashioned, but considerable improvements have been made over those built in the days when steam conditions in coal fire stations were similar, particularly from the point of view of blade materials. Wetness at the low pressure end of the Calder turbines is, however, not excessively high. The alternators are entirely conventional as are the transformers and switch gear.

C. A. Parsons and Co. Ltd.

Each 23 MW turbo generator comprises a 3,000-r.p.m. turbine consisting of a single-flow, 15-stage H.P. cylinder coupled in tandem to a double-flow, L.P. cylinder. Two dump condensers are provided to deal with steam in excess of requirements.

Air Control Installations Ltd.

Alternator cooling fans of the centrifugal double-inlet type.

The Atlas Steel Foundry and Engineering Co. Ltd., Atlas Steel Works, Armadale, West Lothian.

Cast steel cylinder, steam chest and ancillary castings. Supplied to C. A. Parsons and Co. Ltd. and Hick, Hargreaves and Co. Ltd.

Wm. Beardmore and Co. Ltd.

Generator rotor-shaft forgings and balancing ring discs.

Brookhirst Switchgear Ltd.

SC and SC latch-in control equipment for 42 pumps and similar drives ranging from $7\frac{1}{2}$ to 30 h.p.

Clarke, Chapman and Co. Ltd., Victoria Works, Gateshead.

Horizontal H.P. oil ram pumps.

Dorman Long (Steel) Ltd., Zetland Road, Middlesborough, Yorks.

Steel joists and plates for turbo-generators supplied to C. A. Parsons.

English Electric Co., Ltd., Marconi House, Strand, London, W.C.2.

Auxiliary switch gear for turbine hall (A). Two 3,300-V auxiliary switchboards of the OB33L airbreak cubicle type, for the turbine house, comprising 14 and 15 panels respectively.

One 13-panel, 3,300-V auxiliary switchboard for the pump house, of the OB33L airbreak cubicle type.

Two 8-panel 415-V auxiliary airbreak switchboards, type OB3, for the turbine house.

Thos. Firth and John Brown, Ltd., Atlas Works, Sheffield, 4.

Steel forgings for turbo-generators. High and low pressure turbine shafts, generator rotor shafts, runaway stop valves, governor valves, rolled rings for turning gear, and rotor-end caps.

Lancashire Dynamo Group.

Motors for turbine auxiliary drives, fans, pumps, etc. Approx. 85 motors supplied for A: repeat order for B. Horsepower range: 7.5 b.h.p. to 115 b.h.p. Mainly located in turbine hall and basement.

Richard Thomas and Baldwin, Ltd., Wilden, Stourport-on-Severn.

Coreplate for turbo-generator.

Shaw and McInnes, Ltd., Firhill Ironworks, Glasgow.

Cast iron pipework for the cooling-water mains.

Shell-Mex and B.P., Ltd.

Shell turbine lubricating oils.

Sigmund Pumps, Ltd., Team Valley, Gateshead.

Lubricating-oil pumps.

John Taylor Dunford, Ltd., Dean Street, Newcastle upon Tyne.

Thermal insulation for turbines and associated pipework.

Wharton Crane and Hoist Co., Ltd., Reddish, Stockport.

Each turbine hall contains a 60-ton, four-motor overhead electric travelling crane with 78 ft span. The crane is fitted with an auxiliary hoist of 12 tons capacity. The main hoist is designed to lift 60 tons at 5 f.p.m., but a change-speed gear is incorporated to enable it to lift 25 tons at 10 f.p.m.

Electrical Equipment

Bryce Electric Construction Co. Ltd., Kelvin Works, Hackbridge, Surrey.

Current limiting reactors and station transformers. Two reactors connected in the main 11 kV feeders. Oil-immersed, self-cooled with magnetic shielding each rated at 30 MVA; reactance 8%, designed to withstand a fault current of 9,200 A. Four 3,000 kVA and four 2,000 kVA 11,000/3,300V, 3-phase, 50-cycle oil-immersed transformers. Supplied to A.E.A. Value: £41,000.

British Insulated Callender's Cables Ltd., 21 Bloomsbury Street, London, W.C.1.

Supply and installation of 30,526 yd (A) and 15,284 yd (B) 11 kV paper-insulated, lead-sheathed and served power cable; 11,943 yd (A) and 17,356 yd (B) paper-insulated, lead-alloy-sheathed, steel wire armoured and served control cable; 6,874 yd (A) and 9,221 yd (B) multicore telephone cable, insulated, armoured and sheathed. Large quantity of cable fittings and accessories. Main contractor. Approx. value: (A) £150,000 (B) £120,000.

Cable Jointers Ltd., 49 Avenue Road, London, W.3.

Cable jointing.

Micanite and Insulators Co. Ltd., Empire Works, Blackhorse Lane, Walthamstow, London, E.17.

Electrical insulation materials supplied to manufacturers of electrical equipment.

A. Reyrolle and Co. Ltd.

Reyrolle 11-kV metal-clad, horizontal draw-out switchgear. At Calder A there are two separate three-panel 500-MVA boards each controlling one generator, one feeder and one 30-MVA grid transformer. At Windscale there is a seven-panel 750-MVA control panel.

C. C. Wakefield and Co. Ltd., 46 Grosvenor Street, London, W.1.

Transformer oil, 5-6,000 gal, supplied to A. Reyrolle and Bryce Electric Construction.

Instrumentation

Instrumentation of the station can be divided into three main categories. The first group concerns the reactor itself. Neutron flux measurements give a direct reading of reactor power whilst differentiating circuits provide information on the reactor period or rate of power change. Other nuclear instruments are used for determining radiation levels at various parts of the station. Thermocouples are installed at a number of significant points including selected fuel elements and strain gauges indicate changes in dimensions of the reactor vessel and elsewhere. In addition, magslips transmit the position of the control rods to meters in the control room. The second group monitors the coolant for temperature, pressure, flow, purity, level in the storage tanks, etc., to give a complete record of the state of the gas circuits. The reactor control room contains recording and indicating instruments to enable the operators to check on all aspects of the reactor operation. The third group which monitors the steam, turbine and electrical sections, is largely of conventional pattern—a wide variety of measuring devices, meters and recorders being employed. A complete interlocking of all instruments is required to ensure rapid and reliable control throughout the station.

Accurate Recording Instrument Co., Ltd., Garth Road, Morden, Surrey.

Indicating, recording, pressure and temperature instruments including seal oil/gas differential pressure gauges. This is an air-operated instrument having a range of 0 to 10 psi and is suitable for static pressures up to 125 psi. The two pressure responsive elements are multiply brass bellows having all joints silver brazed. The instrument operates on the force balance principle, and the output pressure of 3-15 psi operates an indicator which is located in the same case in the pneumatic device. Special 3 to 15 psi repeater gauges to operate in conjunction with various types of pneumatic transmitters. Transmitting pressure gauges. These instruments comprise an all-welded stainless steel diaphragm transmitter, connected to an all-welded stainless steel pressure gauge by means of stainless steel capillary tube. Depending on the pressure and range, the capillary may be up to 100 ft in length. The system is filled with liquid metal. The object of this type of instrument is to confine the measured fluid to the transmitter and to site the indicator remotely.

Appleby and Ireland Ltd., Kempshott Park, Basingstoke, Hants.

Fine and coarse control rod position indicators utilizing magslips. Approx. 250.

Cambridge Instruments Co. Ltd.

Three electrical distance thermometer outfits comprising three multi-point indicators and two 10-in scale indicators together with thermo-electric pyrometer outfits comprising four multi-point indicators and three 10-in scale indicators. Two 8-in dial index thermometers with contacts for alternator cooling system. Supplied to C. A. Parsons.

E. K. Cole, Ltd., Southend-on-Sea.

Radiation monitors. Ionization chambers and amplifiers.

Costain-John Brown, Ltd., Instrumentation Division, Roxby Place, London, S.W.6.

Supply of four thermocouple logging panels and 12 water leak detection instrument cubicles (A and B). Designed for packaged construction. Main contract. Approximate value: £8,000.

Davison and Co. (Hexham), Ltd., Hexham-on-Tyne.

Vacumeters (mercury column vacuum gauges) for measuring temperatures in the turbine condensers.

Elliott Bros. (London), Ltd., Elstree Way, Borehamwood, Herts.

Elliott 54-point scanning recorders, type ND.51, for monitoring analyses of fuel channels. Each equipment comprises a scanning recorder, an external scanning unit which utilizes a uniselector type of stepping switch and a motor-driven cam which programmes the data sampling and printing sequence and a pen failure alarm unit. The scanning recorder is basically a self-balancing potentiometer unit, with a number of modifications.

General Radiological, Ltd., 15-18 Clipstone Street, Great Portland Street, London, W.1.

Ratemeters for monitoring fuel channels. Model No. 1419A. Also Model No. 1366 start-up unit.

Sir Harold Grubb, Parsons and Co., Ltd., Walkergate, Newcastle upon Tyne, 6.

Infra-red gas analysers for detection of water vapour in CO_2. (Similar equipment for detection of CO_2 in steam.) Supplied to A.E.A. Approximate value: £15,000.

Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, nr. Reading, Berks.

Supply of six health monitors, Type 1457A. For monitoring gamma rays from the reactor. Supplied to A.E.R.E.

George Kent Ltd., Luton, Bedfordshire.

Reactor and conventional instruments including 64 pressure transmitters and indicators (steam), 32 flow transmitters and indicators, 32 drum level transmitters and indicators, 24 pressure transmitters and indicators (CO_2), 62 high-speed electronic multelecs, and 66 multelecs Mk. II (including pH, etc.).

For reactor instrumentation, the instruments applied most frequently are the electronic Multelec high-speed recorder and the microvolt Multelec. Applications are as follow:—

(i) Power level recorder—an electronic high-speed Multelec single-point recorder measuring electrical output from an ion chamber which in turn measures the neutron-flux in the reactor. (ii) Drift recorder which is similar to (i) above, but has means for providing a variable suppression of the zero so that small variations in power level of the reactor can be magnified. (iii) Logarithmic power level recorder. As the output from the pile varies from about one watt to 200 MW it is necessary to provide means of recording power output on a logarithmic basis. To do this, a special logarithmic amplifier has been developed and an electronic Multelec recorder measures the output from the amplifier and records it on a logarithmic scale and chart. (iv) Fuel element temperature recorder: This is a high-speed electronic Multelec for measuring the temperature of selected uranium fuel elements. (v) Gas temperature recorder: This is also measured with a high-speed electronic Multelec. (vi) CO_2 pressure indicators: These are Bourdon-tube-operated electrical transmitters and circular-scale receivers. (vii) Microvolt Multelecs for the measurement of water vapour in CO_2. The primary element in this case was provided by another firm. (viii) Microvolt Multelecs for flux scanning of the reactor: In this application, a tungsten wire is fed into the reactor from top to bottom, and left there for a predetermined time and becomes radioactive in proportion to the neutron flux which passes through it. The wire is then withdrawn and its radioactivity is measured along its length progressively. The microvolt Multelec then provides a graphical record on the chart of the neutron flux at all points throughout the axis of the reactor.

Main contract to A.E.A. Approx. value: £64,000. Small subsidiary orders from C. A. Parsons and A. Reyrolle.

Measurement Ltd., 119 Union Street, Oldham, Lancs.

Flow indicators.

New Western (Engineering) Ltd., 136 Meadow Lane, Leeds.

Panels for control instruments.

R. Y. Pickering and Co. Ltd., Wishaw.

Ionization chambers.

Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Hand and clothing monitor, type 1404A, developed in conjunction with A.E.A.

The Record Electrical Co. Ltd., Broadheath, Altrincham, Cheshire.

Cirscale electric tachometers for remote indication of the speed of the CO_2 blowers. Cirscale milliammeters for use as neutron flux density indicators.

Ernest Turner Electrical Instruments, Ltd., Chiltern Works, High Wycombe, Bucks.

Electrical measuring instruments used as general power level indicators.

Reliance Gear and Engineering Co. (Salford), Ltd., Springfield Lane, Salford, 3.

Precision machine-cut spurs, internals and bevels for control-rod operating mechanisms. Sub-contract to Met-Vik.

TAYLOR WOODROW SUB-CONTRACTORS

Accordo Blinds Ltd. Sun blinds.
Albion Clay Co. Ltd. Cable conduits.
Thos. Armstrong Ltd. Concrete fence posts and sand.

H. Bailey and Co. Ltd. Suspended ceilings. (B).
Barker and Jones Ltd. Facing Bricks. (A).
Best and Lloyds Ltd. Metal balustrading.
Blackburn Brick Co. Ltd. Engineering bricks.
Border Engineering Contractors. Tarmacadam road surfacing.
Bramhall Engineering Co. Ltd. Control-room ceiling lighting panels. (A).
British Reinforced Concrete Engineering Co. Ltd. Reinforcing mesh.
British Trolley Track Co. Ltd. Sliding door gear.
Brookes and Co. Ltd. Metal entrance gates.

George Casson. Sand.
Cement Marketing Co. Ltd. Cement.
Cement (Muffelite) Ltd. Cork mats.
Commercial Marble and Tiles, Ltd. Terrazzo floors.
Concrete Ltd. Precast concrete floors.
Constantin (Engineers) Ltd. F-H Airslide for bulk-cement handling.

Edenhall Concrete Products Ltd. Concrete common and facing bricks. Concrete blocks.
Eskett Limestone Quarries Ltd. Aggregates.
Expandite Ltd. Flexcell expansion jointing.

Falkirk Iron Co. Ltd. Stainless steel sinks.
S. W. Farmer and Son Ltd. Metal balustrading. (A).
Flexo Plywood Industries Ltd. Metal-faced plywood.

Haskins Rolling Shutters. Rolling steel shutters.
F. Haworth (A.R.C.) Ltd. Acid-resisting tiles.
Haywards Ltd. Steel doors.
Hepworth Iron Co. Ltd. Salt-glazed cable conduits.
Hills (West Bromwich) Ltd. Patent glazing, metal windows.
Holloway Metal Roofs Ltd. Copper expansion strip.

Imperial Chemical Industries Ltd. Calcium chloride.

Richard Johnson and Nephew. Chain-link fencing.

F. Labbett and Sons Ltd. Painting.
Limmer and Trinidad Lake Asphalt Co. Ltd. Asphalt.

Manchester Slate Co. Ltd. Asbestos sheeting. (A).
Mather and Platt Ltd. Steel doors.
Matthew Hall and Co. Ltd. Plumbing.
Milners Safe Co. Ltd. Safes.

Nettlefold and Moser Ltd. Door furniture. (A).
Non-Ferrous Die Casting Co. Aluminium-bronze gravity-cast sprinklers.
Northumberland Whinstone Co. Ltd. Aggregates.

Over-Structures Ltd. Tubular welded building framework.

Josiah Parkes and Sons Ltd. Door locks.
C. Parry. Special scaffolding and shuttering.
Plastona Ltd. Granolithic floors. (A).
Pollock Bros. (London) Ltd. Plastering. (A).

N. F. Ramsay and Co. Ltd. Door furniture. (B).
Rawlplug Co. Ltd. Rawlbolts and Rawlites.
W. Richardson and Co. Ltd. Tubular-steel gates. (A).
Robertson Thain. Protected metal roofing.
Ruberoid Ltd. Steel deck roofing.

Shap Granite Ltd. Concrete kerbs, pipes, and fence posts.
Superwood Products Ltd. Joinery and internal timber stacks for cooling towers.

J. Thow Ltd. Glazing. (A).
Triplewoods Ltd. Metal partitions.
Trollope and Colls Ltd. Concrete pipes.
Tubewrights Ltd. Tubular steel gates.
Turners Asbestos Cement Co. Ltd. Asbestos-cement pressure pipes and cladding sheets.

Universal Asbestos Co. Ltd. Asbestos pipework etc. in cooling towers.

Whitecross Co. Ltd. Chain link fencing.
Whiteheads Iron and Steel Co. Ltd. Reinforcing steel.
James Williamson and Sons. Linoleum.
Wottons (Croydon) Ltd. Glazing. (B).

Yorkshire Public Works Co. Ltd. York stone paving.

World News

International

Sixty-one delegates from fourteen countries attended the meeting of the International Organization for Standardization at Geneva in July. The Committee met under the chairmanship of Mr. Paterson, President of A.M.F.; the nine British delegates were led by Mr. H. A. R. Binney, Director of B.S.I. The new I.S.O. is divided into three working groups led by American, British and French chairmen, respectively. These groups will become permanent sub-committees and will deal with the following projects: Development of a tri-lingual glossary of terms applicable to nuclear energy in English, French and Russian. Development of a radiation warning symbol. Adoption of units as developed by the International Commissions on Radiation Protection and on Radiological Units. Development of symbols for drawings. Development of international recommendations relating to measurement and protection. Development of internationally acceptable guides for safe design operation and maintenance of nuclear reactors.

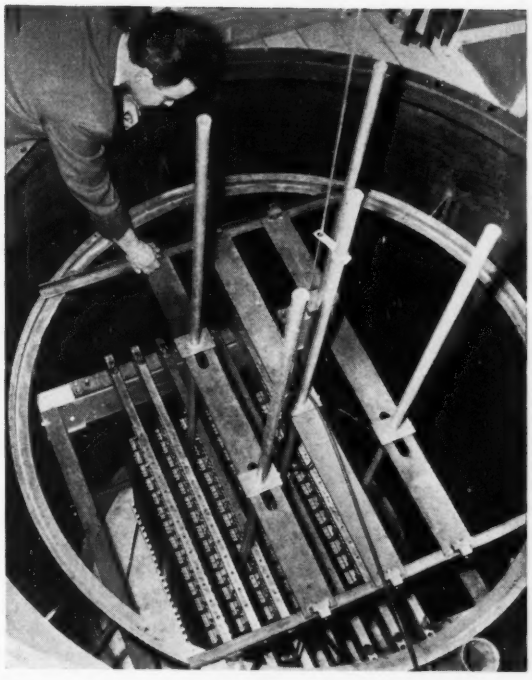
The sub-committee concerned with reactor safety has a United Kingdom secretariat.

An International Conference on radio isotopes is to be held in Paris from September 9 to 20. An attendance of more than 1,000 scientists is expected at the conference which is organized by UNESCO and Sir John Cockroft will preside.

The International Atomic Energy Agency will hold its first meeting in Vienna on October 1. Apart from America, Britain, Russia and France, the following countries have been appointed to the Board of Governors: Japan, India, South Africa, Brazil, Canada, Sweden, Czechoslovakia and Portugal. The Soviet Union has demanded that three senior posts in the Agency must be filled by Russia if the Director-General is a member of the United States. The preparatory commission has proposed that the agency should have a budget of over $6 million and an operational staff of 369. The U.S. contribution is expected to be between 6 and 7 million dollars and this has been approved by the House of Representatives

Although 80 nations have signed the statute setting up the Agency, difficulties are still being encountered in individual countries on its exact terms of reference. The joint Congressional Atomic Energy Committee has approved legislation which forbids the President to allocate fuel without specific Congressional approval. The Indian Premier has talked of " atomic colonialism " resulting from the Agency controlling world supplies of fissile material.

The Second O.E.E.C. course for teachers was held at A.E.R.E. from August 6 to 16. The first of these courses for French speaking teachers began at Saclay on July 15.



A critical facility at Harwell for studying organic moderators. This unit utilizes Dowtherm, a eutectic mixture of diphenyl and diphenyl oxide.

United Kingdom

Sites for the C.E.A.'s fourth and fifth nuclear power stations have now been specified. Permission is to be sought for plants to be erected at Trawsfynydd and at Edern. The first of these sites is already owned by the C.E.A. and lies on the shores of the reservoir for the Maentwrog Hydro-Electric Station which has a sufficient cooling water capacity to feed a 400 to 500 MW station. The Edern site in North Wales is suitable, from considerations of both cooling water and foundations for an even larger establishment.

Approval has at last been given for the Hunterston Nuclear Power Station. The 320 MW plant which will be built by the G.E.C. for the S.S.E.B. will cost £37 million. Preliminary site clearance has already begun.

The North of Scotland H.E.B. has stated that contrary to rumour it is not planning an early start on a nuclear power station in north-east Scotland. Site tests have, however, been carried out in the Crimond area.

Work is to start on a pumped storage scheme as part of the Loch Awe project. The plant will be located at the head of the Crauchan Burn and a capacity of 400 MW is visualized. Investment cost is expected to be in the region of £24½ million.

Bristol University, in co-operation with the University of Minnesota, have detected a particle of energy in the region of 1,000 GeV. The particle, believed to be an α-particle, was detected in a large emulsion stack weighing 300 lb.

The Ministry of Labour and National Service has issued a draft of their proposed regulations for safeguarding workers against the effects of ionizing radiations. Comments on the proposed regulations should reach the Ministry by October 31, 1957, addressed to the Secretary, Ministry of Labour and National Service, 19 St. James's Square, S.W.1.

ZETA the zero energy thermonuclear assembly mentioned in the third A.E.A. annual report was completed in the middle of August, and a discharge set up. A long period of progressive working up to full power is now in hand. The assembly was developed by A.E.R.E. in collaboration with Metropolitan Vickers who also undertook the construction.

The original zero energy tank reactor apparatus which was moved from A.E.R.E. to Dounreay for uranium solution criticality experiments began operating on August 14 as a critical assembly. The programme of research by the R and D branch is aimed at providing empirical data for chemical reprocessing plant.

The 7 GeV proton synchrotron has received financial approval. The cost is expected to be about £7 million. The accelerator is to be built on the airfield at Harwell and will be the main experimental tool of the National Institute for Research in Nuclear Science.

The high temperature gas cooled zero energy assembly is confidently forecast as the first project for Winfrith Heath. A contract for a large part of the design and construction has been awarded to the G.E.C.

The British Association conference will begin in Dublin on September 4. Amongst the many subjects discussed will be power from the fusion process.

Settlement has now been obtained in the patent case concerning the use of various materials for moderating neutrons to increase their effectiveness as transmuting particles. The rights to the original patent were

acquired by Philips Electrical from the original team of owners, headed by Enrico Fermi and including Pontecorvo. It is believed that the U.K.A.E.A. has agreed to pay £10,000, a figure much less than the equivalent A.E.C. amount because of the inclusion in the British patent of a number of strongly absorbing elements amongst the list of moderators.

Australia

Heavy water for HIFAR will be purchased from the U.S. as a result of a recent agreement. Negotiations between America and Australia for co-operation in the field of atomic energy have been long and protracted but all seems now to be well. Difficulties have been largely of a military character.

Belgium

Sir Vincent de Ferranti will preside at a conference in Brussels on May 16 and 17 next year sponsored by BEAMA. The conference is designed to publicize British technical achievements.

A.C.E.C. has negotiated a tie-up with Westinghouse Electric to manufacture nuclear power plants. The agreement covers complete technical information and opens the way for A.C.E.C. to construct pressurized water reactors and other non-military types.

A reprocessing plant for irradiated fuel elements to be set up at Mol has been proposed as an O.E.E.C. venture. The project is still only in the suggestion stage.

Germany

Government legislation is still meeting tough opposition in the Bundestag. An interim bill approved by the cabinet authorizing the construction of research and development reactors up to a power of 15 MW was to be rushed through by the end of August if possible. In spite of the absence of legislation 1.8 kg uranyl sulphate has been delivered from the U.S. for the Frankfurt water boiler.

Heavy water production is to start soon at the Farbwerke Höchst A.G., near Frankfurt. When in full operation the plant is to have an annual production of up to 10 tons. The separation principle is distillation at low temperatures and reports have suggested that the process contains certain features which make it more economical than was at one time believed possible.

Reactor siting arguments have arisen between the East and West Berlin City Authorities. West Berlin is planning a research reactor near Babelsberg which the East German government maintains will be a threat to the population.

The valley which will hold the lower reservoir of the pumped storage plant—the largest in the world, now under construction near Blaenau Ffestiniog.

Ground was broken last month on the A.M.F.-Mitchell 15 MW closed cycle boiling water reactor power station site at Dettingen near Frankfurt-Main. For details see pages 378-380 this issue.

Hungary

Gallium can be extracted by a novel process " to yield pure metal at a comparatively cheap rate," according to a newspaper account of details released by Dr. Jozsef Uveges of the Hungarian Metal Research Institute. Gallium is found in the lye used in processing bauxite into alumina, and it is believed that one kg metal can be produced from 10 cu.m of lye. So far 30 g have been separated. Gallium, with a melting point of 29°C and a boiling point of over 2,000°C could be a valuable heat transfer medium for cooling reactors if large quantities were available at prices comparable with those obtaining for sodium.

The water-moderated reactor at the Nuclear Physics Institute in Rumania.

India

A plan for a comprehensive power reactor programme is to be placed before the government by the middle of next year. This was stated by Dr. Bhabha on the anniversary of the starting up of the first reactor at Trombay. The reactor, operating at power levels of from 1 to 100 kW, has now run for 1,500 hours. Dr. Bhabha is quoted as stating that India could build her own nuclear power station by 1962.

Italy

Four large-scale power reactors are planned to be in operation by 1962. The World Bank has agreed to finance a 150 MW station in Southern Italy probably between Cassino and the Garigliano river. The plant will be run by SENN (Società Elettro Nucleare Nazionale) and tenders are to be invited from U.S. and U.K. companies whilst the U.S.A.E.C. and the U.K.A.E.A. have offered technical help. It was announced on July 31 that ENI (Ente Nazionale Idrocarburi) has concluded agreements with both the U.K.A.E.A. and Vitro Corporation of America each for the construction of a

nuclear power station. The first of these is through Agip Nucleare for the construction of a Calder-type plant probably in North Italy. It is expected that a contract will be placed before the end of the year. The second will be built by SIMEA either in Central or Southern Italy with full assistance by Vitro. SELNI is also planning a nuclear power station.

Also on July 31 it was announced from Turin that the Fiat Co. had signed an agreement with Westinghouse of America for the production of nuclear power stations. It would appear that this arrangement is similar to that concluded with A.C.E.C. of Belgium.

The Euratom and European common market plans were ratified by the Italian Chamber of Deputies at the end of July.

Rome's municipal power authority is to purchase a 12.5 MW nuclear power station from the International General Electric Co. of America to power the 1960 Olympic Games.

Japan

Delay and indecision still seems to be the keynote of Japan's nuclear power station proposals. Conflicting reports of imminent decisions continue to arrive but the team from the English Electric have returned with only assurance that the Calder type appears to be the most developed. Another Japanese mission is to visit Britain later this year.

A new power corporation is to be formed to import and control nuclear stations. The new body will comprise members of Electric Power Resources Development Corporation, nine regional power companies and the Atomic Energy Institute and will be mainly government financed.

New Zealand

The Minister of Mines, Mr. John McAlpine, has implied that the recent survey of the Buller area in the South Island had indicated the presence of significant workable uranium deposits. Exploitation could, he added, radically change the country's economy.

Norway

The Norwegian Institute for Atomic Energy and the U.K.A.E.A. have recently signed an agreement for co-operation in connection with the Norwegian Halden project. It is understood that in return for supplying fuel and co-operating on some aspects of design, full design and operational information will be given.

Sixteen tons of heavy water were delivered from the U.S.A. to Oslo for the Halden reactor at the beginning of August. The uranium from the U.K. will arrive later this autumn. It is expected that initial run-up trials of the boiling heavy water system will be completed in time for the '58 Geneva conference.

Rumania

A reactor of the light water moderated type, rated at 2 MW, has been run up to criticality at the Nuclear Physics Institute of the Academy of Sciences. The reactor is similar to other reactors supplied by Russia to Eastern bloc countries.

Cores for two reactors for Germany being fabricated by Atomics International.

Spain

A swimming pool reactor rated at 3MW is to be shipped to the Junta de Energia Nuclear by General Electric now that the A.E.C. has issued an export permit. The U.S. government contributes $350,000 to the project which also includes the erection of laboratories and buildings. Value to G.E. is $449,969.

An agreement with the United States to expand co-operation between the two countries was signed on August 16. Under the agreement Spain will now be able to receive enriched uranium, and information on power reactors.

Switzerland

Energie Nucléaire the new society in Lausanne plans the construction of a 20MW boiling water reactor driving a 5MW generator through a secondary steam circuit. The plant is to be installed in a cave near Lausanne and will be a feature of the 1964 Swiss National Exhibition.

Meyrin: The 600 MeV synchro-cyclotron is now operating at full power at the research centre for CERN. The accelerator is the first of two that will be the basic physics tools for higher energy particle research. The second —the 25 GeV proton synchrotron—is due to come into operation in 1960.

U.S.A.

The Maritime Administration in co-operation with the A.E.C. has invited industry to make proposals for the development of a nuclear power plant suitable for merchant ship propulsion consisting of a gas-cooled reactor coupled to a closed cycle gas turbine. This is a continuation of the programme under which feasibility studies have been completed by General Motors, Ford Instrument, Sperry Rand and General Atomic. The invitation anticipates that a contract will be placed covering development work of five to seven years' duration.

Permits for the construction of 17 educational reactors have been granted to Aerojet-General Nucleonics. These reactors which operate in the milliwatt range contain elements of uranium oxide dispersed in polythene. Complete cores are pre-irradiated in a linear accelerator beam.

Cuts have been made by the A.E.C. in the price of radioactive cobalt. The new price ranges from $2 to $5 per curie as against $50 for the first 2 curies and $2 to $10 per curie thereafter. Source handling charge has been raised from $10 to $100 with discounts for bulk purchases to encourage private distribution.

First shipment of radio isotopes to Russia in the form of carbon-14 compounds has been announced. The U.K. has of course been exporting isotopes behind the iron curtain for many years.

SRE is now undergoing operational trials, power having first been generated on July 15. The reactor is rated at 20MW (heat) and 6,500 kW(E). In the first tests the generator was run at an output of 1MW.

Uranium production for the first half of this year was 60% up on the same period last year—4,200 tons high grade concentrate as against 2,600. It is estimated in the 22nd semi-annual report that the annual production figure by 1958 should be 14,000 tons.

The APPR has completed 700 hours operational running. Contract for this plant was awarded to Alco Products Inc. in December, 1954. The company has a working agreement with Humphreys and Glasgow.

The first development power reactor licence is to be issued to General Electric for operation of a power reactor in Alameda, California. The facility is a boiling water reactor with a thermal heat output of 20MW and an installed capacity of 5MW. The prime purpose of this scheme is to furnish technical data for the full scale system G.E. is building for Commonwealth Edison. Original application was made on January 10, 1956, but has been subject to modifications.

Orbits in Industry

WELDING is very much in the limelight of late. It plays, for example, a not inconsiderable part in that two-yearly function which, in spite of its ever-changing title, people *will* refer to as the "Eng. and Marine" or (worse still) the "Marine Engineering Exhibition," and it keeps on popping up all over the place, which, considering the tremendous part it plays in engineering generally, and nuclear engineering in particular, is hardly surprising.

Yet it is not really so very long ago that "welding" was an operation carried out by a blacksmith, and even in the early 1920s it seemed to be still in its infancy. Most manufacturing concerns regarded welding as a method of substituting for a casting when it was a one-off job that couldn't stand the cost of a pattern. Looking back at some of the early welding, with its irregular burns and blobs of metal, so reminiscent of a householder's first attempt at soldering an enamel saucepan, and seeing the final component, bowed and twisted as if it had been poisoned by strychnine, one could see their point of view. More than one concern returned to casting after a more or less brief period of fabricated assemblies. Nevertheless, the welding boys won through and, as experience was gained in the design of welded assemblies, as well as in the actual process, welding became first accepted, then taken for granted, then indispensable. It took a long time to persuade the conservatively-inclined that a welded boiler drum was a practical proposition. Now it is realized that—quite apart from the impossibility of riveting thick plates—welding is a lot safer for the thin plates, if only from the point of view of eliminating corrosion under the butt straps.

Resistance Movement:

Resistance welding, too, had an uphill fight in the early days. When pressure, current, and time could vary independently—and continuously—at the whim of the operator, the weld might be right, it might be practically burned through, or it might be one of those "nominal" welds which are all right until you breathe on them. Tangent has memories of one of those keep-fit-if-it-kills-you rowing machines where the spring anchorage plate was secured (?) by a weld of this description. This was afterwards changed to a rivet, following a demonstration which included, on the part of the unlucky demonstrator, a couple of ground loops and a pancake landing that were not in the script. Yet resistance welded tube was used for the Calder Hall heat-exchangers. One could hardly have a more convincing proof than this of the tremendous change in outlook that has taken place.

Education in Welding:

Most technical subjects get more complicated as time goes on, and welding is no exception. At one time it was a simple operation. Having been issued with an eyeshield and a handpiece, one first of all forgot everything the instructor had said and "froze" the electrode to the work. One then, by a superhuman effort, wrenched it free, jabbing the instructor in the eye with the butt end, and carried on from there.

The supreme test for a weld, in those days, was whether it stuck or not. Microscopes and X-rays would have been considered rather unsporting—like shooting a sitting bird. Now that we have invented all sorts of things like hydrogen inclusion, hot cracking, and brittle fracture, and users of welding want to make helium-tight joints in metals that have hitherto been regarded as unweldable, not only do we require welders to know something about the subject—a lot of other people must know, too.

To be serious for a moment, it is scarcely necessary to emphasize the importance of adequate education in welding and its associated problems, not only for the operators but for designers and executives. The last two present special difficulty because the type of course envisaged is a rather special one and the type of man is one whose time is valuable. Mr. G. Parsloe, secretary of the Institute of Welding, in commenting on the new School of Welding Technology, which the Institute is organizing (page 388) pointed out that the average run of evening classes usually attract the younger men rather than the type the Institute has in mind. The Universities also will only cater for them in the form of courses that are much too long for them to be spared, whereas the Institute's new course has been specifically designed with the time factor in view.

Although it is early days to prophesy, it seems more than possible that this might develop into a permanent school with its own staff of full-time lecturers. This, however, is something for the more or less remote future—it cannot be foreseen as a "stone ginger" at present.

Immaculate Labs:

One of the first items of interest gleaned on our visit to the British Welding Research Association (page 386) was that the main laboratory building was designed according to the plastic theory developed by Prof. Baker of Cambridge, reminding us of our visit there last month.

One of the most striking features of the entire visit—irrelevant to the main issue as usual—was the condition of the electrical laboratories. Fundamental instruction can be carried out on old machines just as well as on the very latest types; better, in fact, because old machines are more liberally rated, less cluttered up with gadgets, and much more get-at-able. Consequently, much of the basic machinery in many institutions is frequently what one would describe as Early Cromptonian period, and the Cambridge labs were no exception. But the condition! Few operating theatres could be more scrubbed, polished and dustless; no exhibition machine at Olympia or Earls Court could show such gleaming steel and glossy paint. Even the brass nameplates, bearing the names of makers long dead or absorbed into other groups, glittered like something that the Goldsmiths Company had just knocked up for a retiring Lord Mayor. How is it done?

Playing From The Gallery:

Our too-ready imagination (and how cross our private psychopath gets at times!) was recently stirred by a correspondent's reference to the "Minstrel's Gallery" at Calder Hall. Sternly fighting down visions of the operations staff with blacked-up faces and banjos, singing "Swanee River," we concentrated on the other type of minstrel, those who enlivened Tudor evenings with what Shakespeare called ". . . the vile squeaking of the wry-necked fife . . . ." From there it was but a step to consider the compatibility, as it were, of music and nuclear fission; only to find that little research had been done from the nuclear standpoint. From the musical end only one relevant reference could be unearthed. Milton in *Il Penseroso* pointed out that

". . . . Such notes as warbled to the string
Drew iron tears down Pluto's cheek. . . ."

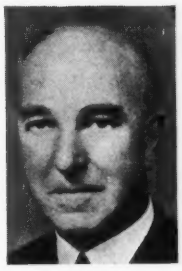
Which, of course, settles the matter. Even though it refers to a different reactor, nobody is going to run the risk of ferrous contamination just for the sake of music while you work. So strings are obviously out, leaving only wind instruments. Curiously enough, that is just what they were; it turned out that the romantic-sounding name referred to the location of the shield cooling fans. So it was probably a misprint for "mistral" anyway. The rumbling noise in the background is just the collapse of another cherished theory.

Tangent

Sir C. Hinton.

Mr. C. R. King.

Sir Henry Self.



Sir Josiah Eccles.

Prof. R. S. Edwards.

Personal

Appointments

Sir Christopher Hinton, K.B.E., M.A., D.Eng., M.I.C.E., M.I.Mech.E., M.I.Chem.E. F.R.S., has been appointed chairman of the Central Electricity Generating Board, which was set up under the Electricity Act, 1957. Sir Christopher, who is 56, is managing director of the Industrial Group of the Atomic Energy Authority. **Mr. C. R. King,** C.B.E., Comp.I.E.E., M.Inst.F., chairman of East Midlands Electricity Board since 1948, becomes deputy-chairman of the new Generating Board. Other members of the Board include **Mr. F. H. S. Brown,** B.Sc., M.I.Mech.E., M.I.E.E., chief engineer of the C.E.A., and **Mr. E. E. Long,** F.S.A.A., F.I.M.T.A., F.C.I.S., secretary of the C.E.A. A further four to six members have yet to be appointed.

Sir Henry Self, K.C.B., K.C.M.G., K.B.E., deputy chairman of the C.E.A., becomes chairman of the new Electricity Council. His deputies are **Sir Josiah Eccles,** C.B.E., M.M., D.Sc., M.I.C.E., M.I.E.E., M.I.Mech.E., deputy chairman (operation) of C.E.A. and (part-time) **Professor R. S. Edwards,** aged 47, Professor of Economics, with special reference to industrial organization, in the University of London. **Lord Citrine,** P.C., K.B.E., Ll.D., Comp.I.E.E., previously chairman of the C.E.A., becomes a part-time member of the Council. The Council is to have up to two more members, in addition to the chairman of the Generating Board, two members of the Board and the twelve Area Board chairmen as ex-officio members.

Mr. L. J. Saywood as sales engineer of Wayne Kerr Laboratories Ltd. He was formerly a senior engineer in the export division of Marconi Instruments Ltd.

Mr. W. A. Flint has joined the sales promotion department of The Drayton Regulator and Instrument Co. Ltd. to handle publicity.

Mr. J. F. Herbert, B.Eng., as manager, overseas atomic projects, for The English Electric Co. Ltd. He has also been elected a director of The English Electric Export and Trading Co., Ltd.

Mr. P. W. Faulkner, O.B.E., as general manager of the chemical and metallurgical division of The Plessey Co. Ltd. at Towcester. He is also a director of Technical Ceramics Ltd.

Mr. E. C. Uren as chairman, **Mr. W. M. Johnson** as deputy chairman and **Mr. P. W. E. Holloway** as managing director of Holloway Bros. (London) Ltd.

Mr. J. B. Dennison as president of the Institution of Mining and Metallurgy.

Mr. T. C. Cleveland as acting manager, Export Department, E. K. Cole, Ltd.

Mr. J. S. Harper as manager of Mono Pumps new office at 77 Great Victoria Street, Belfast.

Mr. G. G. Roberts, M.Sc., A.F.R.Ae.S., formerly director of research to Smiths Aircraft Instruments Ltd., becomes technical director upon the resignation of Mr. E. B. Moss.

Mr. W. H. Richards as production superintendent of Marconi Instruments Ltd.

Mr. P. W. Cash, B.Sc.(Eng.), A.C.G.I., M.I.E.E., system design and development engineer of the C.E.A. as system operation engineer at headquarters.

Mr. S. W. Simmons and **Mr. A. E. Cain** have joined the board of Dekko Cameras.

Mr. J. W. Berry as deputy managing director of Birmid Industries Ltd. **Mr. W. J. Sully,** joint managing director of Sterling Metals, and **Mr. W. C. Jordan,** deputy managing director of Birmetals, have been appointed directors. **Mr. A. E. Pearce** and **Mr. H. Goodwin** retired from the Board on July 31.

Tours

Members of the English Electric-Babcock and Wilcox-Taylor Woodrow companies recent mission to Japan included: **Mr. J. F. Herbert,** manager overseas atomic projects, and **J. Cameron,** commercial officer atomic power projects, The English Electric Co. Ltd.; **Mr. A. Reisner,** Babcock Hitachi Kubushiki Kasha, and **Mr. W. R. Wootton** assistant manager, atomic energy department, Babcock and Wilcox Ltd.; **Mr. A. J. Hill,** chairman and managing director, and **Mr. D. A. J. Ballinger,** director, of Taylor Woodrow Construction Ltd.

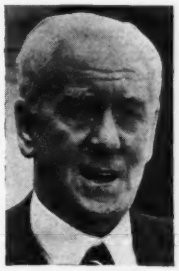
Captain F. G. Wayman, chairman and managing director of Rocol, Ltd. and **Mr. George J. Vineall,** director of research, are making an intensive sales tour of the principal engineering cities in the U.S.A. The company proposes to establish a network of sales agencies.

Awards

Mr. R. S. Hall, of Birmingham University, has been awarded the *Nuclear Engineering* Scholarship for 1957. With the aid of the scholarship, which is worth £400, Mr. Hall expects to carry out research on reactor physics.

Mr. E. E. Long.

Mr. F. H. S. Brown.



Lord Citrine.

Mr. J. F. Herbert.

Mr. P. W.Faulkner.

New Books

An Introduction to Reactor Physics. By D. J. Littler and J. F. Raffle. (220 pp. Pergamon Press, 30s. net.)

The second edition of this book (Vol. I, Division X of the "International Series of Monographs on Nuclear Energy") has now appeared. It is stated that no great change of content has been made from the first edition which, based on lectures at the Reactor School, Harwell, has proved very popular. Most of these changes, consisting of the correction of certain sections and the amplification and rearrangement of others have been for the better although this is doubtful in the case of the section dealing with moderators.

In general, however, there is a tendency to include much detail which could well be omitted from a book which is intended to be an introduction to the subject while some of the basic concepts, considerations or limitations of reactor theory might have been dealt with more fully. Despite the claim that sufficient reactor theory is given to enable the reader to understand the problems involved in designing thermal reactors, other than the natural uranium, graphite-moderated type, the book does not deal with the conditions for which a heterogeneous array is necessary to obtain criticality with the various possible moderators; nor is it shown for what conditions enrichment of the fuel is necessary. The reason why air gaps should be introduced into a reactor (Chapter 10), when their inclusion seems to be detrimental, is not discussed, nor is the reason why graphite was chosen as the moderator for several reactors.

The chapter on "Pile Kinetics" has now been corrected, but deals with kinetics for only half its length, the other half dealing with the effect of an absorber on the static behaviour of a reactor and with the approach-to-critical experiment. Chapter 12, "Running a Pile at Power" deals for several pages with the temperature coefficients of reactivity in a reactor, but fails to stress the very important feature of the natural uranium, graphite-moderated reactor—its inherent stability due to these temperature effects.

There are some misleading statements: for example, the definition of "age" given in the footnote on page 86, the section on page 168 regarding the desirability of making the value of RC short compared with the shortest electron collection time and that on page 169 regarding the constancy of gas amplification with variation of voltage applied to a proportional counter. It is also not clear from the book why a thin foil should be used in a fission chamber (page 176), nor why no mention is made of the γ-sensitivity of some neutron detectors and the difficulties arising therefrom in the measurement of reactor flux.

The book is in danger on the one hand, of failing to make the basic considerations of reactor theory sufficiently clear, while on the other hand not sufficing as a textbook of reactor design.

Russian-English Atomic Dictionary. Edited by Dr. Eugene A. Carpovitch. (317 pp. Technical Dictionaries Co., New York, $12.)

The publication of a new Russian-English Dictionary of terms used in nuclear physics and chemistry, and some allied sciences, will be welcomed by students of Soviet literature on these subjects. Recently published in New York, the dictionary has the merit of being freely available, unlike the earlier dictionary of this kind which was brought out in Moscow two years ago. Its scope moreover is considerably wider. Dr. Eugene A. Carpovitch, who edited this work, was responsible for an English-Russian Electro-technical Dictionary originally published in Moscow in 1939, and he has edited for the U.S. Army an English-Russian, Russian-English Electronics Dictionary.

In a comparatively new field, in which words are continually being coined to describe new phenomena as they are observed, Soviet texts must be carefully analysed to establish current usage, and the extensive bibliography which precedes the main body of this dictionary is indicative of the care which Dr. Carpovitch has brought to this task.

Comprising over 23,000 Russian entries, the dictionary primarily covers nuclear science and nuclear technology, including theory, reactors, instrumentation, and isotopes but it also includes a useful selection of terms used in physics, chemistry, mathematics, metallurgy, biophysics and medicine, together with words found in the literature of computers and electronics in general. Finally, students who have been hard put to it to identify Western scientists whose names are transliterated into Cyrillic will appreciate the inclusion of Russian versions of these names.

Dr. Carpovitch's dictionary is remarkably compact for its scope and the number of entries it contains, in spite of the fact that the editor seems, at times, to have assumed a somewhat limited knowledge of science on the part of its users. The repetition of certain terms would appear to be superfluous; for example, a scientist who is familiar with the expression "carbon tracer" would hardly need seperate translations for the expressions "phosphorous tracer," "chemical tracer," or "tracer method"; the same could be said about Be_3N_2, Th_3N_4 and ZrN_2. But this is hardly justifiable criticism of a dictionary which at last provides the student with the correct translation of the Russian for such expressions as "ordered alloy," "power engineering" and "plane wave." Its publication will greatly facilitate the study of the Russian literature in the fields it covers, and it is to be hoped that its appearance will encourage British scientists in the first-hand study of texts which cannot wholly or quickly be made available in translation.

The New World of the Atom, by James Stokley. (288 pp, 30 illus. Ives Washburn Inc., New York, $5.50.)

In writing for the layman it is all too easy to be thorough and boring or to be bright, interesting and practically uninformative. Mr. Stokley succeeds in avoiding both courses. He has distinguished between "layman" and "moron," and produced a book that could confidently be recommended to the serious minded who have no knowledge of nuclear matters and wish to get an insight into what is happening and what effect it is going to have on them and their world, without either wading through a mass of mathematics or being, in effect, told not to ask awkward questions. How the author manages to explain matters clearly and simply, without skipping the hard bits, is his own secret.

Commencing with "The New Science" the book reviews the beliefs of the ancients on the atom, and through the original work the nucleus and the development of the fission process, it takes in the world's need for energy, reviews "official" and "private" reactors in the U.S. and abroad, and the problems of radioactivity. The concluding sections "The New World" and "The New Spirit" are not, as might be imagined, by any means fanciful or overdrawn.

Concise Encyclopedia of Atomic Energy. Edited by Frank Gaynor. (204 pp. Peter Owen, Ltd., 50 Old Brompton Road, London, S.W.7, 37s. 6d. net.)

This is rather more than a collection of brief definitions and explanations of terms used in the nuclear field, and includes a number of charts and tables ranging from a conversion table for energy units to tables of isotopes and nuclear spin quantum numbers. It also gives the German equivalents of a large number of the topics.

The sole criticism that one would make is that it was, to judge from the author's preface, first published in the U.S. in 1950 and, although it is stated that a number of revised editions have been issued in the U.S., the ephemeral information (such as tables of reactors, etc.) is badly out of date, e.g., Britain is quoted as having GLEEP and BEPO. Although it is obviously impossible to keep a publication right up to date in an industry which moves so rapidly, one feels that at least a few insertion leaflets would not have come amiss.

Industrial Notes

Manufacturing Agreements

Negotiations are reported regarding the possibility of a merger between **General Dynamics Corporation** and the **Liquid Carbonic Corporation,** on the basis of Liquid Carbonic becoming a division of General Dynamics. Liquid Carbonic is said to be the world's largest producer of carbon dioxide and the fourth largest producer of oxygen and acetylene in the U.S.

Taylor, Taylor and Hobson Ltd. of Leicester, and **A. Kershaw and Sons** of Leeds are to be integrated under one management. Both are members of Rank Precision Industries Ltd.

From July, 1957, **Clark Equipment International C.A.** has become an equal partner with the **Austin Motor Co. Ltd.** and **Crompton Parkinson Ltd.** in **I.T.D. Ltd.** an established organization marketing "Stacatruc" and "Electricar" vehicles. The Clark Equipment Co. has six factories in the U.S.

Holman Bros., Ltd., of Camborne, Cornwall, and **Climax Rock Drill and Engineering Works, Ltd.,** now consider that a complete merger of the two companies would be to the advantage of the Holman Group. Holman have held a controlling interest in Climax since 1951.

The Crawford Fitting Co. of Cleveland, Ohio, has joined the consortium that is planning the Case Industrial Nuclear Centre at Glenwillow near Cleveland. The others include the Austin Co., the Cleveland Electric Illuminating Co., the Clevite Corporation, the Republic Steel Corporation, Schenley Industries Inc., the Standard Oil Co. of Ohio, and Thompson Products Inc.

Turner Manufacturing Co. Ltd. of Villiers St., Wolverhampton, have formed a subsidiary company Hydraulics and Pneumatics Ltd. who will manufacture a range of components under an agreement with the Modernair Corporation of America.

The Solartron Electronic Group Ltd. has decided not to continue selling through agents in the U.K. All inquiries should be sent direct to their headquarters at Thames Ditton, Surrey.

Stewarts and Lloyds, Ltd., are to build a factory for the production of electric-resistance-weld tubes of from $6\frac{5}{8}$ in. to 16 in. o.d., adjacent to the rolling mill of **John Summers and Sons, Ltd.,** at Shotton.

Contracts

A.P.V.-Paramount Ltd. of Crawley, Sussex, have received a contract from the General Electric Co. Ltd. (Atomic Energy Division), for steel castings to form the guide pans through which the control rods are lowered into the reactor core, for the South of Scotland Electricity Board station. The castings, of which several hundred are required, weigh 800 lb. each and are required of an unusually high quality steel to rigid limits of dimensional accuracy.

A. C. Wilson and Partners Ltd. an associate of the Power-Gas Corporation Ltd. are undertaking a series of projects for the U.K.A.E.A. Projects already in hand include the irradiated fuel element laboratory for Windscale; the experimental loop breakdown cave for DMTR; the fuel element pond facility for Dounreay; and the blanket stripping cave for the fast reactor chemical separation plant at Dounreay.

Albright and Wilson (Mfg.) Ltd. of 1 Knightsbridge Green, London, S.W.1, are operating the Kaningen plating process on a production scale in Britain and are also the sole licensees in Eire and Denmark. This process, consisting of the electro-deposition of a nickel-phosphorous alloy, can be applied to most metals and to glass, ceramics, and thermosetting resins. It has been approved by both the Ministry of Supply and the Air Registration Board.

S. I. M. A. Convention. — The Scientific Instrument Manufacturers Association is holding its sixth Annual Convention at Eastbourne, from October 24-27. Four separate discussion panels will discuss, respectively, "European Free Trade—A Challenge"; "Presentation and Publicity"; "Methods and Materials for Tomorrow"; and "Neucleonics"; it being the first time that a new branch of instrumentation is being made the subject of a complete convention panel.

Benson-Lehner (G.B.), Ltd., has now taken over many of the functions of the British Division of the Benson-Lehner Corporation of Los Angeles. The new company—located at 12 Bargate, Southampton, supplies scientific data processing equipment including strip chart analyzers and automatic graph plotters.

The British Tyre and Rubber Co. Ltd. of Herga House, Vincent Square, London, S.W.1, announces that from September 16, its name will change to **BTR Industries Ltd.**

The Institute of Marine Engineers moved on August 17, from 85 Minories, E.C.3, to The Memorial Building, 76 Mark Lane, E.C.3.

Lee Guinness Ltd. is to have a second factory for automatic control gear near their existing works at Newtownards, Co. Down, The Northern Ireland Development Council has announced that work is to begin on the new factory at an early date.

Fielden Electronics Ltd. announces that it is to open a north-eastern sales and service office at Stockton-on-Tees on September 5.

George Kent Ltd. founded 119 years ago have now closed down the retail domestic machinery side of their business and rebuilt their premises at 199 High Holborn as a showroom exclusively devoted to industrial instrumentation.

(Right) The new George Kent industrial instrument showroom at High Holborn, London.

(Left) To improve the reliability of their products even further, AVO Ltd., have introduced a dust-free, air-conditioned zone within which instruments are built, calibrated, and tested, under ideal working conditions. All personnel entering the zone must comply with exacting standards of cleanliness.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 773,021. Nuclear reactor elements. To: Brown, Boveri and Co. Ltd. (Switzerland).

The elements, rods or tubes of uranium, are surrounded by a closely fitting and completely closed sheath filled with an intermediate material consisting of 44.5% lead and 55.5% bismuth (by weight) with a melting point of 125°C. This material is liquid at the operating temperature and produces a good heat transmission between the fissionable material and the sheath.

B.P. 773,541. Joints for use in pipelines and between parts of vessels. J. P. A. Macdonald. To: Crane Packing Ltd.

For corrosive, noxious or toxic fluids. The one-piece jointing element is formed from a ring with a deep internal slot affording a certain flexibility in the direction of its thickness although of normally non-resilient material. Continuous serrations or corrugations are provided on the opposite faces of the ring to fit into recesses formed in the opposing ends of the pipelines or vessel parts between which the ring is clamped.

B.P. 773,563. Manufacture of electric cables. L. G. Brazier, R. M. Black. To: British Insulated Callender's Cables Ltd.

The dielectric around the conductor is a laminated body built up from strips of insulating material impregnated with a liquid organo polysiloxane which gels after completion of the impregnation when subjected to high energy radiation. Suitable polysiloxanes are the poly-dimethyl-silicone oils. The high energy radiation may be carried out in a nuclear reactor and consists then of slow neutrons with associated fast neutrons and gamma rays of an intensity of not less than 10^{14} thermal neutrons/cm²-min.

B.P. 774,052. Method and device for the production of energy from exothermal chemical or nuclear reactions. P. Schmidt (Germany).

Conversion of substances, e.g., of hydrogen into helium, requires extremely high temperatures and pressures. The new method produces such temperatures and pressures by pressure shock waves with a comparatively limited technical equipment. These shock waves occur in detonations and in the movement of bodies and gases in the supersonic range and their use for this method is based on the discovery that the energy embodied in the shock wave and progressing with it is concentrated to higher temperatures and pressures when the shock waves converge. Observations made in the investigation of pressure waves show that the compressibility of water at pressures of over 50,000 kg/cm² is much higher than would be expected from an extrapolation of the static values measured at low pressures, and that a crushing of the atomic electron shells is commencing. In the range of extremely high concentrations of the energy of pressure shock waves the nuclei are liberated and nuclear conversion occurs. The method is carried out in a hollow sphere filled with an elastic compressible medium (hydrogen). Pressure waves are produced in quick succession in the form of concentric spherical waves meeting at the centre of the hollow sphere For a sphere diameter of 2 m and radial impulse velocities of 10 to 100 m/s and only small pressure increments, temperatures in the centre of the sphere are calculated to reach 10^6 to 10^9 °K.

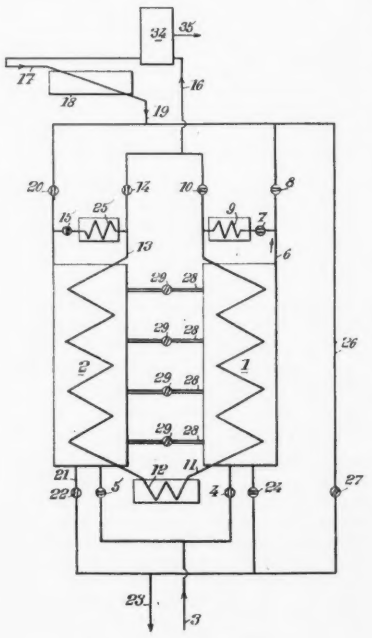


Fig. 1.—B.P. 774,255.

B.P. 774,136. Method and apparatus for detecting leaks in pipelines. J. F. Cameron, S. Jefferson. To: U.K. Atomic Energy Authority.

A radioactive solution is injected into fluid flowing in the pipeline behind which a first squee-gee go-devil is introduced. After an interval sufficient to enable the non-radioactive solution to flush the inside of the line clear of radioactivity a second squee-gee go-devil is introduced with a radioactivity recording detector. This detector is recovered at a remote point and the record of any activity is then transcribed in terms of distance along the line. To check the distance, the record may be marked at intervals by arranging sources of radioactivity at certain points along the line which will make a characteristic signal. For penetrating thick metal pipes gamma radioactivity is necessary and detectors with Geiger counters or scintillation detectors.

B.P. 774,130. Injector pump for conveying liquids. J. D. Thornton. To: U.K. Atomic Energy Authority.

In order to avoid moving parts the liquid is pumped through an injector arranged below the surface and is pulsated so that the surface oscillates about a mean position. During the positive half-cycle of a pulse, liquid is forced through the injector nozzle so that the liquid is pumped from the main intake to the injector outlet. During the negative half-cycle the liquid flows in reverse without pumping action. For feeding, e.g., liquid to an extraction column or mixer-settler tank against a static head in liquid-liquid extraction plants (with pulsed column according to B.P. 756,049 (N.E. 1956 Vol 1(9) p.400 (Dec)).

B.P. 773,771. Metal sheathing of solid bodies. W. O. Alexander. To: U.K. Atomic Energy Authority.

Uranium rods or slugs are introduced into tubular metal containers (aluminium alloys with manganese (up to 2%) or magnesium (up to 5%) of a wall thickness of 0.01 to 0.03 in. The container may be open on both ends or on one end only. The open ends are turned over around the rod or slug body and also around the head of a rivet backing on the body. The closure is produced by riveting the shank of each rivet over the turned-in end. To obtain a close fit of the sheath, the container may, after introduction of the body, be reduced by cold drawing, pressing or otherwise. The body (uranium rod) is preferably of cylindrical form with plain ends from 3- to 12-inch length and 1-inch dia and is fine machined. To minimize danger of escape of fission products, a double sheath may be employed.

B.P. 774,255. Cold separation of gas mixtures. R. Spondlin, L. Stouls, H. Bonnaud, G. Simonet. To: Commissariat à l'Energie Atomique (France).

The invention is shown in an application for the purification of hydrogen containing small amounts of nitrogen, in an installation for manufacturing deuterium by liquefaction and rectification. Fig. 1 shows (diagrammatically) the layout of a purification apparatus with two exchangers 1 and 2, of the "Hampson" type, the envelope of which will resist the pressure of the hydrogen (30 at). The impure hydrogen arrives through pipe 3 (valve 4 open, valve 5 closed). It enters the space between the casing and the tubes and issues through pipe 6. The hydrogen then passes through coil 9 (valve 7 open, valve 8 closed) immersed in a bath of liquid hydrogen boiling under one atmosphere. It again enters exchanger 1 (valve 10 closed) but inside the tubes, issues through pipe 11 and passes through coil 12 immersed in a bath of liquid nitrogen in the presence of its gaseous phase and in equilibrium therewith at a temperature equivalent to that of the hydrogen entering through pipe 3 (e.g. 63° K.). The nitrogen is therefore under a pressure of 9 cm of mercury. It then passes through the tubes of exchanger 2 and issues through pipes 13 and 16 (valve 14 open. valve 15 closed) under pressure to rectification column 34. The hydrogen under low pressure (one atmosphere) separated in the rectification column from its deuterium (evacuated through pipe 35) flows out through pipe 17. Before leaving it is heated by passing through cooler 18 where there is a counter-current flow of liquid hydrogen under 3 at. It issues through pipe 19, enters the space of heat exchanger 2 between casing and tubes, issues through pipe 21 and leaves the installation through pipe 23. In the next period the positions of the valves are reversed.